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Final Report to
Federal Emergency
Management Agency
June 1988

Capacity Vulnerability Indicators for Strategic and Critical Materials

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A systematic approach was developed for assessing capacity "pinchpoints" and their vulnerability for strategic/critical materials. The approach is grounded on the comparative statics framework of microeconomics coupled with engineering assessment on the capability of the industrial sector to respond in the short term to overseas supply curtailment. Various aspects of the approach are illustrated for selected commodities including chromium, cobalt, manganese, platinum, titanium, and natural rubber.

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EXECUTIVE SUMMARY

Background

The Strategic and Critical Materials Stock Piling Act provides that a stockpile of strategic and critical materials be held to decrease dependence upon foreign sources of supply in times of a national emergency. Events in recent years, both economic and technological, have changed the composition of the U.S. industrial base and the capacities to utilize and produce various forms and quality levels of strategic and critical materials and stimulated the development of substitutes in some industrial processes. Because of these changes, the appropriate forms of materials to be stockpiled could also potentially change.

Objectives

As a result, this study was undertaken to develop a procedure ("methodology") which could be used to identify the relative vulnerability of selected commodities to curtailment by considering such factors as domestic sources of material, capacity availability, substitutes, etc.

A process flowsheet methodology was developed that:

- used data sources in the open literature to estimate DOD and civilian sector demands;
- can be applied (with some modifications) to different commodities and thus ensures a uniformity of approach;
- develops a capacity vulnerability index by use of the process flowsheet; and
- provides for an examination of historical trends in terms of the vulnerability index.

Findings

The required data elements, namely identification of product forms/quality, U.S. capacity estimates and U.S. demand breakdown allow for the construction of a capacity vulnerability analysis chart for each product form. This approach is simple to construct, offers a common format for analysis and is easy to interpret. Examples of capacity vulnerability comparisons can be found in Figure 3.2, Figure 3.3 and the appendices. Vulnerability regions were defined. The main purpose of these regions is to establish a point of reference in a comparative mode between commodity materials/processes/forms. In addition, these capacity vulnerability regions can be used to designate the positioning of a so-called capacity "pinchpoint" threshold (i.e., minimum acceptable capacity).

All of the materials evaluated in this study are ones where much, if not most, of the raw materials are imported.

Using the methodology, illustrative vulnerability assessments were conducted for:

- manganese,
- titanium,
- cobalt,
- chromium, and
- the platinum group

For each of the above, the following product forms were considered as appropriate.

- ore,
- metal,
- oxide,
- chemical,
- ferroalloy,
- metal (catalytic)
- metal (non-catalytic)

Of the eighteen material process/form combinations analyzed in this study, seven or 39% of the total were classified as "not vulnerable," the rest, 61%, had some degree of vulnerability as indicated by the two comparison vulnerability assessment charts.

Not surprisingly, ore/mining of manganese, cobalt, and the platinum group metals were judged to be "extremely vulnerable." This is primarily due to the low grade, if any, domestic ore bodies and concomitant lack of economic incentives to tap these resources. Interestingly, of all the materials studied, three out of four cobalt process/product forms had some degree of capacity vulnerability by this analysis.

Although Figure 3.2 is fairly "busy" with data points and representative symbols, this chart shows that it is possible to evaluate numerous strategic or critical materials with a uniform and consistent methodology.

A comparative analysis of materials in this study is presented in Section 3.3. Again, an arbitrary "cutoff" or "pinchpoint threshold" has been chosen for the purposes of describing this methodology. Opportunities to provide a historical trend of vulnerability (e.g., 10 year tracking of peacetime condition) is also an easy task given that realistic and somewhat accurate data for the input exists. Finally, based on capacity vulnerability alone and an arbitrary "pinchpoint" analysis, quality and form options for stockpiling can be highlighted.

This report is arranged to facilitate easy access to first, the approach and methodology used to analyze strategic or critical materials, and, secondly, the comparison of these materials' overall vulnerability. Vulnerability analyses and supporting documentation are arranged for each strategic or critical material in the appropriate appendix. The comparison of the relative vulnerabilities for each material product (i.e., manganese-ferromanganese) and related process (i.e., manganese-smelting) is discussed in Section 3.

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TABLE OF CONTENTS

Arthur D. Little, Inc.

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

The Strategic and Critical Materials Stock Piling Act provides that a stockpile of strategic and critical materials be held to decrease dependence upon foreign sources of supply in times of a national emergency. Executive Order 12155 vests the primary responsibility for planning the stockpile program in the Director of the Federal Emergency Management Agency (FEMA).

There are 93 forms of strategic and critical materials presently held in the National Defense Stockpile (NDS). These forms represent all stages of industrial processing and varying levels of quality arrived at over a number of years in response to technological changes of the times. Events in recent years, both economic and technological, have changed the composition of the U.S. industrial base and the capacities to utilize and produce various forms and quality levels of strategic and critical materials and stimulated the development of substitutes in some industrial processes.

1.2 PURPOSE AND SCOPE

The purpose of this study was to develop a systematic approach to be applied to strategic and/or critical materials for determination of production capacity vulnerability. A capacity/demand "pinchpoint" analysis for each material/form/quality combination is then possible. In addition, a process for addressing material substitution and its impact on manufacturing capacity is developed.

This demonstrated methodology is capable of being applied uniformly to a wide range of materials both in determining existing capacity vulnerability and monitoring historical trends. Analysis generated using this methodology should be useful in determining stockpile options related to material form and quality.

1.3 ORGANIZATION OF THE REPORT

This report is arranged to facilitate easy access to first, the approach and methodology used to analyze strategic or critical materials, and, secondly, the comparison of these materials' overall vulnerability. Vulnerability analyses and supporting documentation are arranged for each strategic or critical material in the appropriate appendix. The comparison of the relative vulnerabilities for each material product form (i.e., manganese- ferromanganese) and related process (i.e., manganese-smelting) is discussed in Section 3.

2.0 APPROACH

2.1 INTRODUCTION

The approach to developing a methodology for assessing the relative vulnerability of strategic and critical materials supply focused on:

- Domestic demand and domestic or foreign supply,
- Segmentation of domestic demand into material product forms and quality requirements for SIC economic sectors,
- Segmentation of domestic demand by major end-users, such as estimated DOD demand, secondary DOD demand (essential civilian), and basic civilian demand,
- Assessment of domestic capacity to produce a given strategic material product form (e.g., manganese-ferromanganese), and
- Strategic and critical material process flow "pinchpoint" analysis.

All of these factors were incorporated into the capacity vulnerability analysis for chromium, cobalt, manganese, titanium and the platinum group. A less in-depth evaluation of vulnerability for natural rubber is given in Appendix I.

The necessary methodology for collecting technical information and classifying technical developments to evaluate direct substitution or conservation issues affecting strategic or critical materials is provided in Appendix B. <u>However, for emergency and near-term strategic and critical material demand, direct substitution approaches are unlikely to have significant impact</u> (see Section 2.5).

2.2 DOMESTIC DEMAND BY MAJOR END-USE

The basis for evaluating the vulnerability of strategic/critical material supply is estimating the domestic demand by customer group and by market as follows:

Total Domestic Demand

- By customer group
  - domestic output directly to defense,
  - domestic output directly to military construction, and
  - domestic output of secondary flows to defense (e.g., aircraft tires or auto parts sold to third party who then sells it to the defense sector). This is designated in the capacity vulnerability analysis as "essential civilian" demand. See Appendix A for details.
- By end-use market (economic sector)

- Transportation,
- Machinery,
- Communication,
- Etc.

This segmentation of the domestic demand was accomplished using publicly available information and databases to estimate DOD dependency on strategic/critical materials. The methodology for tracking DOD-related demand was based on:

- Bureau of Mines' information on tonnage flows of commodities to various SIC economic sectors,
- The relationship of SIC sectors to INFORUM economic sectors, and
- INFORUM information on dollar flows between the various economic sectors (both input and output).

Total estimated DOD-related demand (i.e., direct, military construction and secondary flow) is computed in dollars and estimated in tons. An example of this computation for total domestic cobalt demand is shown in Appendix A.

2.3 DOMESTIC AND FOREIGN SUPPLY

Strategic/critical material supply information was obtained through public sources, such as the U.S. Bureau of Mines' publications, current industrial reports, and trade associations like the Ferroalloy Association. Evaluation of domestic supply included:

- Ore, concentrates, or raw material grades,
- Number and location of sources,
- Scrap recycling rate,
- Processing capacity for intermediate forms from raw material to final product,
- Potential domestic sources, and
- Historical trend of key processing capacity.

Evaluation of foreign supply included:

- Material form and quality,
- Major sources, and
- Degree of reliance on foreign imports (under peacetime conditions) by material form.

2.4 MATERIAL FORM FLOWSHEETS

For each strategic/critical material evaluated in this study, a product form/process stage flowsheet was developed such as in Figure 2-1. The product form flowsheet indicates each process stage, associated intermediate product form, degree of foreign supply dependence and potential process capacity pinchpoints for the representative materials studied.

Process flows in Figure 2-1 lead to major end-use products that are consumed, for example, manganese ferroalloys in steel, manganese metal for alloying, manganese dioxide used in battery applications and manganese used in the production of consumer chemicals.

This product form flowsheet makes it easier to see the cause and effect relationships between supply (capacity) "pinchpoints" and their downstream effects on intermediate or end-product demand sectors.

2.5 FRAMEWORK FOR ANALYSIS: SUPPLY/DEMAND ELASTICITIES

The comparative statics framework of microeconomics provides a starting point for analysis. We start with a fairly simple, straightforward representation of market equilibration by drawing the appropriate supply and demand curves. For a given commodity, the supply curve shown in Figure 2-2 is composed of two elements: domestic supply S (D) and foreign supply S (F). To be of interest to this study, a significant portion of the supply of a commodity (or upstream form of the commodity) must be from foreign sources. Clearly, if the domestic supply curve is such that further domestic output could be supplied at only modest price increases, under a curtailment scenario, then the U.S. is less vulnerable than if the reverse (inelastic) situation were to occur. This supply can be constrained in the short term by capacity limitations at any stage in the production process, especially in the short term of up to 3 years since it would take this long to bring on significant new capacity. We view this in terms of a capacity-demand "pinchpoint" analysis described more fully in Appendix C.

A similar examination of the demand by market sector would show that for some materials, essential DOD-types of demand may be highly inelastic while the commodity being used in other markets might be highly elastic. For example, titanium used in supersonic aircraft might represent a highly inelastic demand because there are no other materials that can satisfy these functions at the same level of performance. However, the use of titanium in some heat exchangers may be highly elastic since other materials, like stainless steel, may be used. **Thus, demand elasticity is often conditioned by the nature of the specific end uses and the availability of alternative materials and other demand shifting factors such as population, income, etc.**

These demand functions are shown in Figure 2-3.

- D_1 represents conceptual DOD demand which is highly inelastic since over the time frame considered here (up to 3 years), it is felt

FIGURE 2-1:
PRODUCT FORM FLOWSHEET

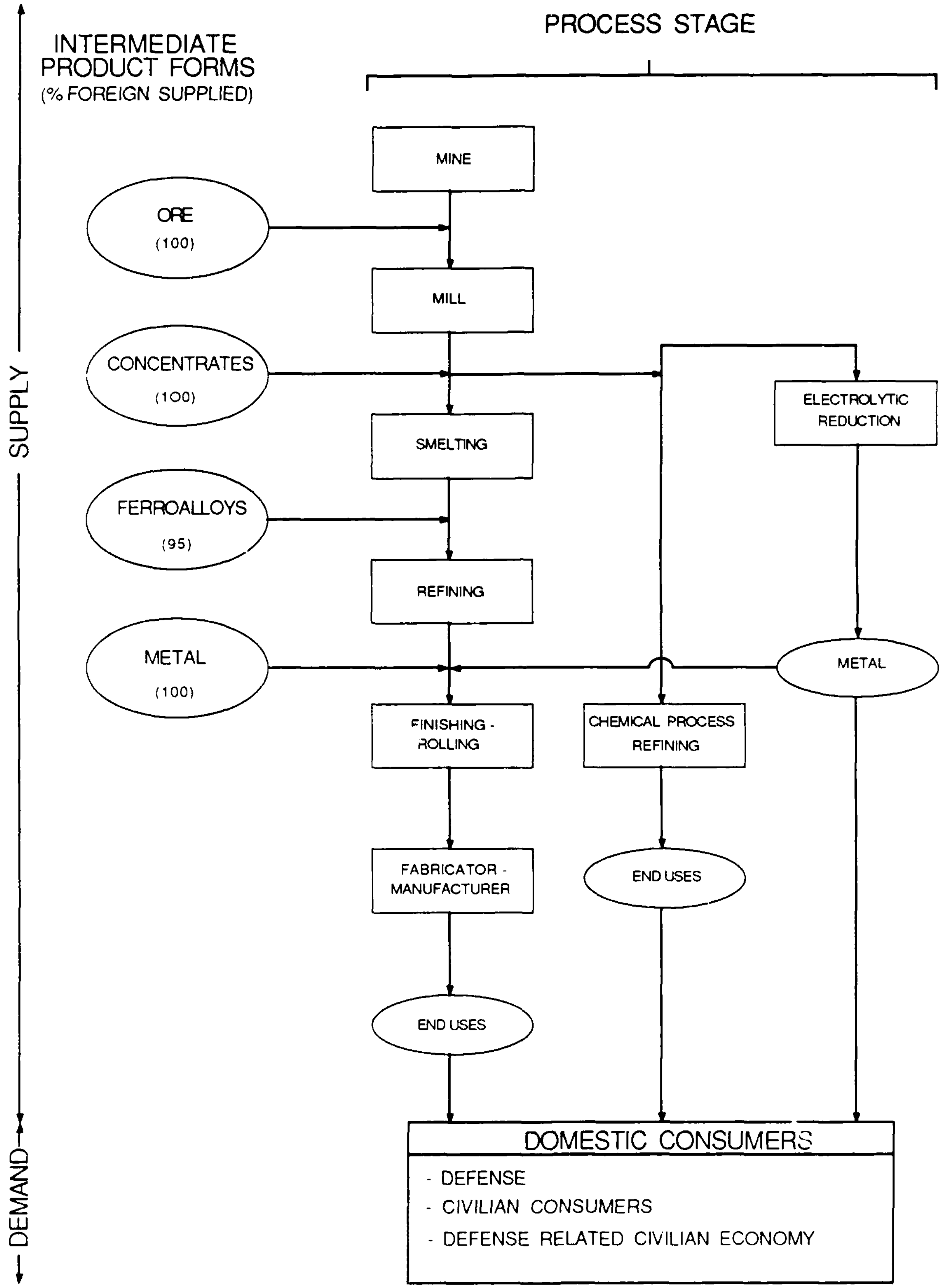


FIGURE 2-2: SUPPLY CURVES

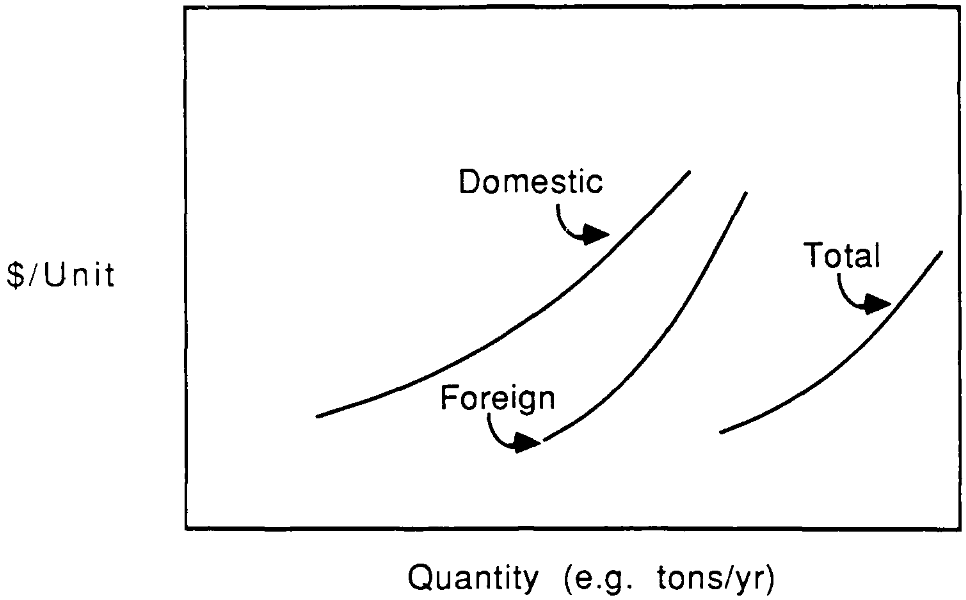
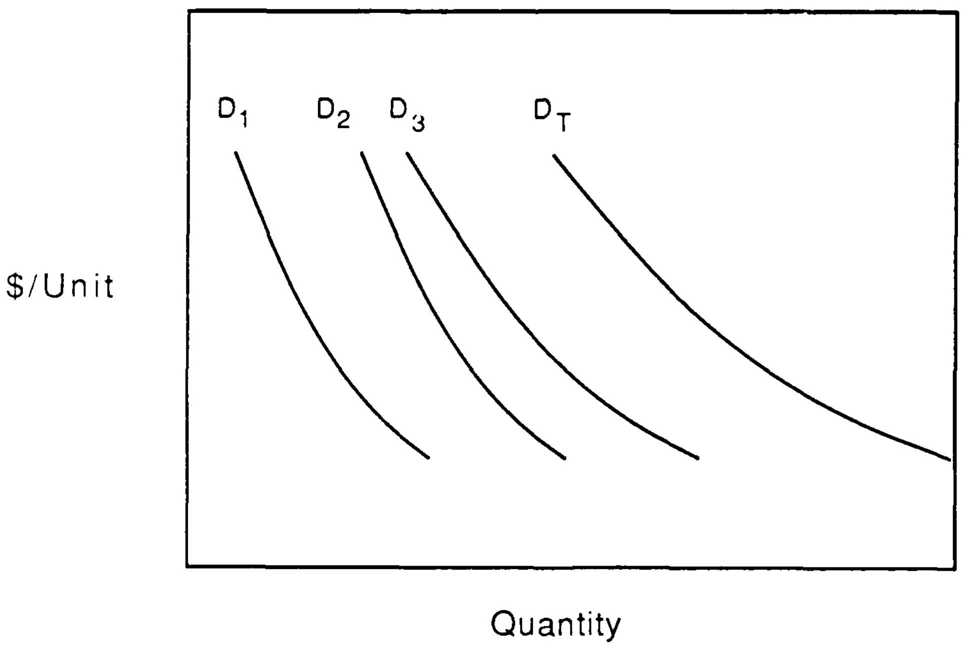


FIGURE 2-3: DEMAND FUNCTIONS



D_1 Highly Inelastic (e.g. DOD Demands)
D_2 Highly Inelastic Civilian Demands
D_3 Other Demands
D_T Total Demand

that few DOD specifications, applications, or procurement policies could be realistically changed.

- D_2 represents highly inelastic secondary or "essential civilian" demand.

- D_3 represents other, "non-essential" civilian demand, showing considerable elasticity.

- D_T represents total demand, the sum of D_1, D_2 and D_3.

Under an emergency or crisis scenario, one might expect the DOD and other essential civilian demand to increase. Thus, the demand curve shifts out from D to D' due to the new DOD-types of demand (Figure 2-4). **In a three-year emergency scenario, however, it is unlikely that key users would accept substitute and untested materials in their armaments, transportation, communication or other systems which accounts for it being represented as a highly inelastic demand.**

The basis for supply vulnerability analysis can be stated as follows:

- Assume 100% curtailment of foreign imports.

- Canadian supplies are considered secure.

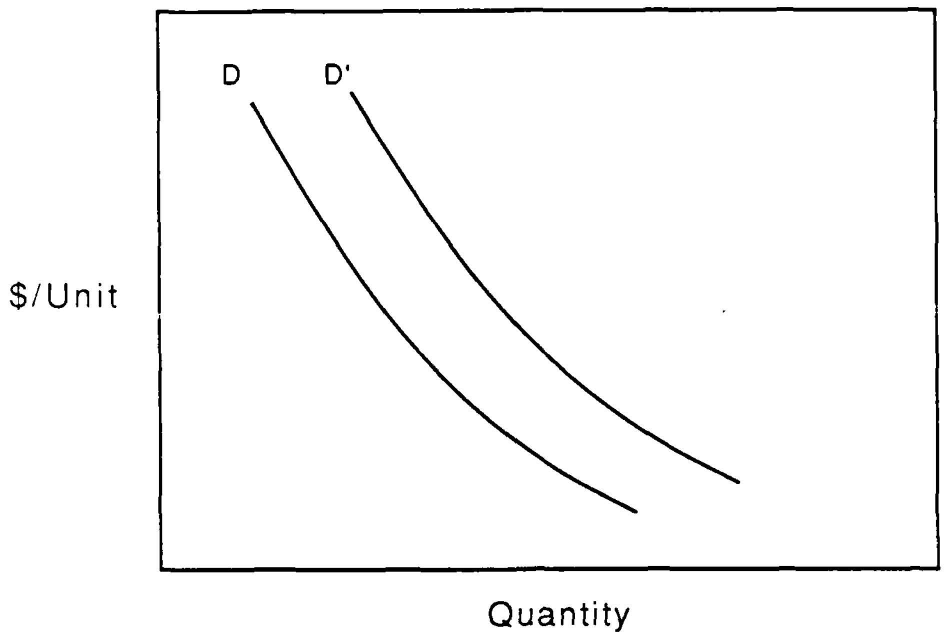
- The time frame for analysis is a three-year emergency:

  - Limited time to build new mines or plants which would significantly add to the production base over the long-term, but is not considered to have a meaningful impact for the time frame of this study and is thus neglected.

  - Existing facilities/mines can be expanded up to their "name plate" capacity, and

  - Specification and adoption of alternative (substitution) materials is a very limited option for the emergency (three-year) time frame, since specifications and testing of substitutes followed by design and building of new substitute-based manufacturing capacity would probably involve a time frame of greater than 3 years.

FIGURE 2-4: OUTWARD PUSH ON DEMAND CURVE DUE TO EMERGENCY



2.6 VULNERABILITY PLOTS

Capacity vulnerability is assessed by comparing the capacity/demand balance for any particular form (or quality) of strategic material(s). The capacity vulnerability plot for manganese ore mining, for example, is shown in Appendix D, Figure D-5. The "civilian demand ratio" (i.e., non-essential civilian demand (D_3) divided by domestic capacity (C) to mine manganese) is plotted against the "DOD and Essential Civilian Demand Ratio" (i.e., estimated DOD (D_1) plus essential civilian (D_2) divided by (C) domestic capacity). When both demand/capacity ratios fall below a value of one for a particular material/form/quality combination, no demand/capacity imbalance exists. Above this line, some measure of imbalance in U.S. domestic capacity and demand does exist. "ISO vulnerability" regions were calculated using the supply/demand balance equation derived in Appendix C and assuming arbitrary elasticity coefficients that reflect a more inelastic nature to DOD and essential civilian demand compared to non-essential civilian demand. These arbitrary elasticity coefficients are chosen purely for the illustrative purposes of this developed methodology for assessing capacity vulnerability. These calculated regions of capacity vulnerability can be "repositioned" based on more current or valid econometric data. For the purpose of this analysis, they serve as comparative "benchmarks."

3.0 ANALYSIS AND CONCLUSIONS

3.1 Introduction

The analyses and developed methodology are designed as a vulnerability screening tool for strategic and critical materials. This study is not intended to be a quantitative or definitive treatment of all the issues surrounding stockpile material form/quality, but rather a method for uniform comparison of a wide range of materials. Some of the data used in these analyses was unsubstantiated and therefore subject to error, but the capacity vulnerability methodology was uniformly and consistently applied to all materials analyzed. A capacity vulnerability analysis for each process/product form was the basis for determining capacity "pinchpoints." These analyses fed into a capacity based vulnerability assessment depending on form of the material. Critical issues other than process capacity, form quality and material substitution regarding ultimate stockpile material priorities are not addressed in this study.

3.2 Using the Methodology

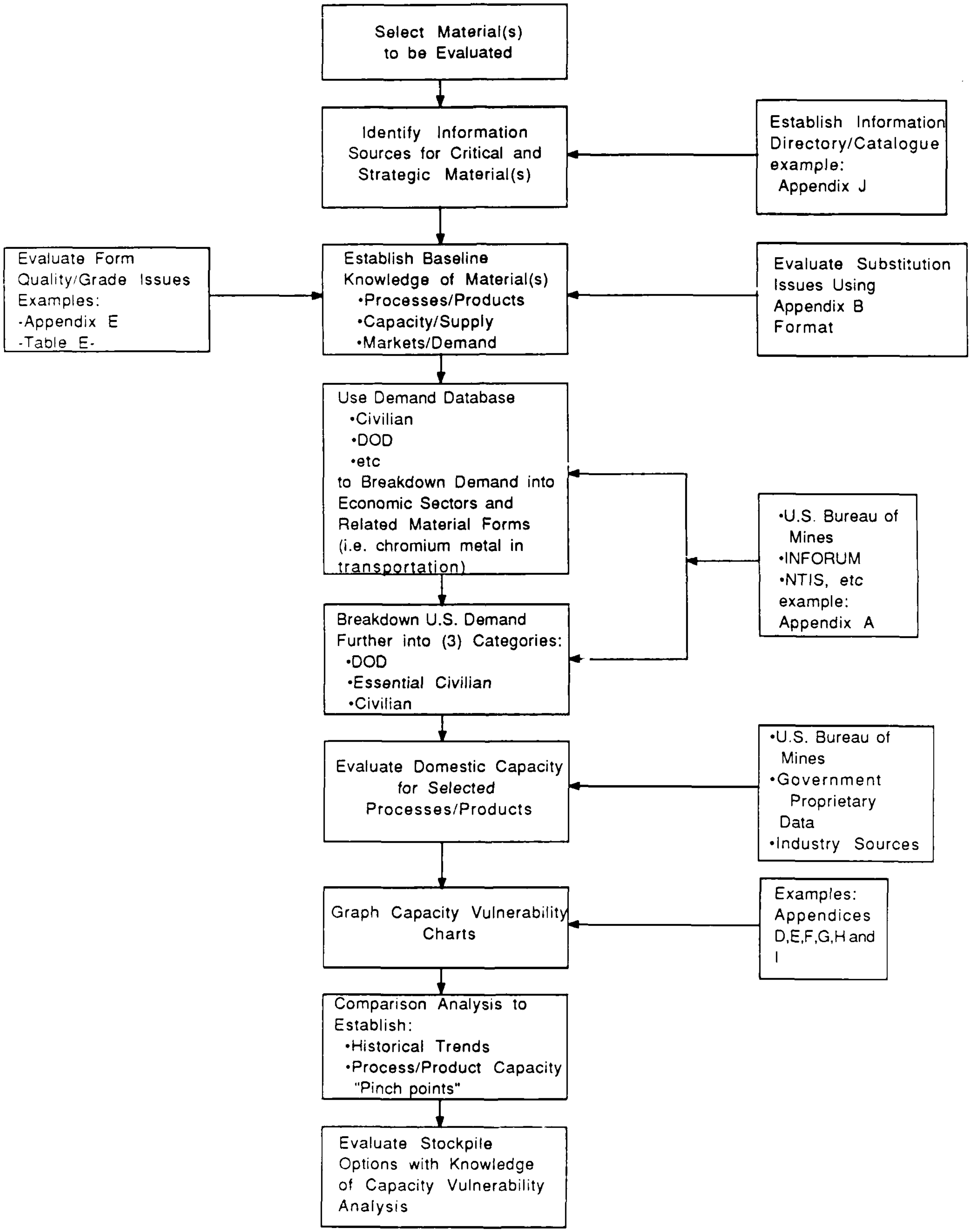
A process flow methodology for uniform and consistent application to materials was developed and summarized in Figure 3-1.

After material selection, the first step is to identify necessary information sources to establish a baseline knowledge of the pertinent processes/product forms, supply/capacity data (domestic and foreign), markets/demand (domestic and foreign), etc., for each material. Examples of such an effort are the material profiles in Appendices D, E, F, G, H and I, and the Literature Directory shown in Appendix J. In addition, issues regarding substitution of a competing material can be addressed using the prescriptive methodology in Appendix B. For example, the rather rapid substitution of polymeric based composites for conventional metallics such as aluminum in aerospace markets can be evaluated and "tracked" using this approach. Evaluation of raw or intermediate material quality or grade specifications are to be a part of this established knowledge baseline. This is covered in each material profile of this report.

The next step in the use of existing or obtainable databases (i.e., U.S. Bureau of Mines, DOD, INFORUM, NTIS, etc.) is to break down U.S. domestic demand into economic sectors (i.e., transportation, machinery, chemical, etc.). This demand must then be related to the particular material processes/forms such as ore, metal, chemicals, etc. In this study, one form was chosen to best represent the consumption of a particular economic sector (i.e., chromium metal for the transportation sector). Using open source data (i.e., INFORUM and U.S. Bureau of Mines) the dollar flows for:

- direct to defense and military construction (described as estimated DOD-D_1),
- secondary flow to defense (described as essential civilian - D_2), and
- civilian demand for an economic sector (described as civilian - D_3)

FIGURE 3-1
Flowsheet For Capacity Vulnerability Methodology Usage



are converted into tonnage flows for each economic sector. It should be noted that with some exceptions, only secondary flows were estimated (see Appendix A for discussion).

The required data elements, namely identification of product forms (quality), U.S. capacity estimates, and U. S. demand breakdown allow for the construction of a capacity vulnerability analysis chart for each product form. This approach is simple to construct, offers a common format for analysis and is easy to interpret. Examples of capacity vulnerability comparisons can be found both in this section and the appendices. Arbitrarily set vulnerability regions (more vulnerable with increased shading) can be adjusted by changes in the elasticity coefficients (see Appendix C). The main purpose of these regions is to establish a point of reference in a comparative mode between commodity materials/processes/forms. In addition, these capacity vulnerability regions can be used to designate the positioning of a so-called capacity "pinchpoint" threshold (i.e., minimum acceptable capacity).

A comparative analysis of materials in this study follows in Section 3.3. Again, an arbitrary "cutoff" or "pinchpoint threshold" has been chosen for the purposes of describing this methodology. Opportunities to provide a historical trend of vulnerability (e.g., 10 year tracking of peacetime condition) is also an easy task given that realistic and somewhat accurate data for the input exists.

3.3 Vulnerability Assessment: Comparison of Critical or Strategic Materials

Using the methodology that was described in Section 3.2, a vulnerability assessment was compiled in Figures 3-2 and 3-3 for:

- manganese,
- titanium,
- cobalt,
- chromium, and
- the platinum group

In addition, the following product forms are identified (as applicable):

- ore,
- metal,
- oxide,
- chemical,
- ferroalloy,
- metal (catalytic)
- metal (non-catalytic)

Of the eighteen material process/form combinations analyzed in this study, seven or 39% of the total were classified as "not vulnerable," the rest, 61%, had some degree of vulnerability as indicated by the two comparison vulnerability assessment charts.

Figure 3-2 illustrates a useful way to summarize the approach used to assess vulnerabilty. The figure provides a map showing for a given commodity (or its form):

- DOD demands as a ratio of domestic capacity along the horizontal (X) axis, and

- Civilian demands as a ratio of domestic capacity along the vertical (Y) axis.

Thus, for any commodity or its form, one can identify a point on the map illustrated by Figure 3-2. Points falling on different parts of the map indicate different degrees of vulnerability. For example, a commodity represented by points falling in the:

- Lower left-hand corner (Sector I) indicate a region of low vulnerabilty. Domestic supplies can meet civilian and DOD demands under peacetime and emergency conditions where foreign supplies are curtailed;

- Upper right-hand corner indicate a region of extreme vulnerability. In this region (Sector IV), domestic supplies cannot meet civilian and DOD demands. As a result of curtailment from foreign supplies, extreme shortages can be expected to occur.

- Lower right-hand corner (Sector III) indicate a region of high vulnerability because DOD demands cannot be met if foreign supplies are curtailed. While less of concern than the sector IV "extreme vulnerability," commodities falling in Sector III need to be examined closely.

- Upper left-hand corner (Sector II) indicate a region of modest vulnerability. Civilian sector demands cannot be met from domestic supply sources but DOD demands can. As a result, points falling in Sector II are labelled "modestly vulnerable."

A specific example of highly vulnerable commodities is illustrated in Figure 3-3. Both cobalt metal and platinum ore fall into a highly vulnerable region. Domestic resources and upgrading facilities are small and cannot begin to meet DOD and civilian demands under conditions of import curtailment.

Figure 3-4 shows how some of the other commodities are mapped in this study indicating smaller degrees of vulnerability than in Figure 3-3.

Finally, Figure 3-5 shows a blowup of the left-hand, lower corner of Figure 3-4 to provide detail on commodities that fall into the borderline area of Sectors I, II, and III.

Although Figure 3-5 is fairly "busy" with data points and representative symbols, this chart shows that it is possible to evaluate numerous strategic or critical materials with a uniform and consistent methodology. The scope of this project was to develop and demonstrate a methodology. The data and analysis represented in Figures 3-2 through 3-5 are

FIGURE 3-2

VULNERABILITY SECTORS

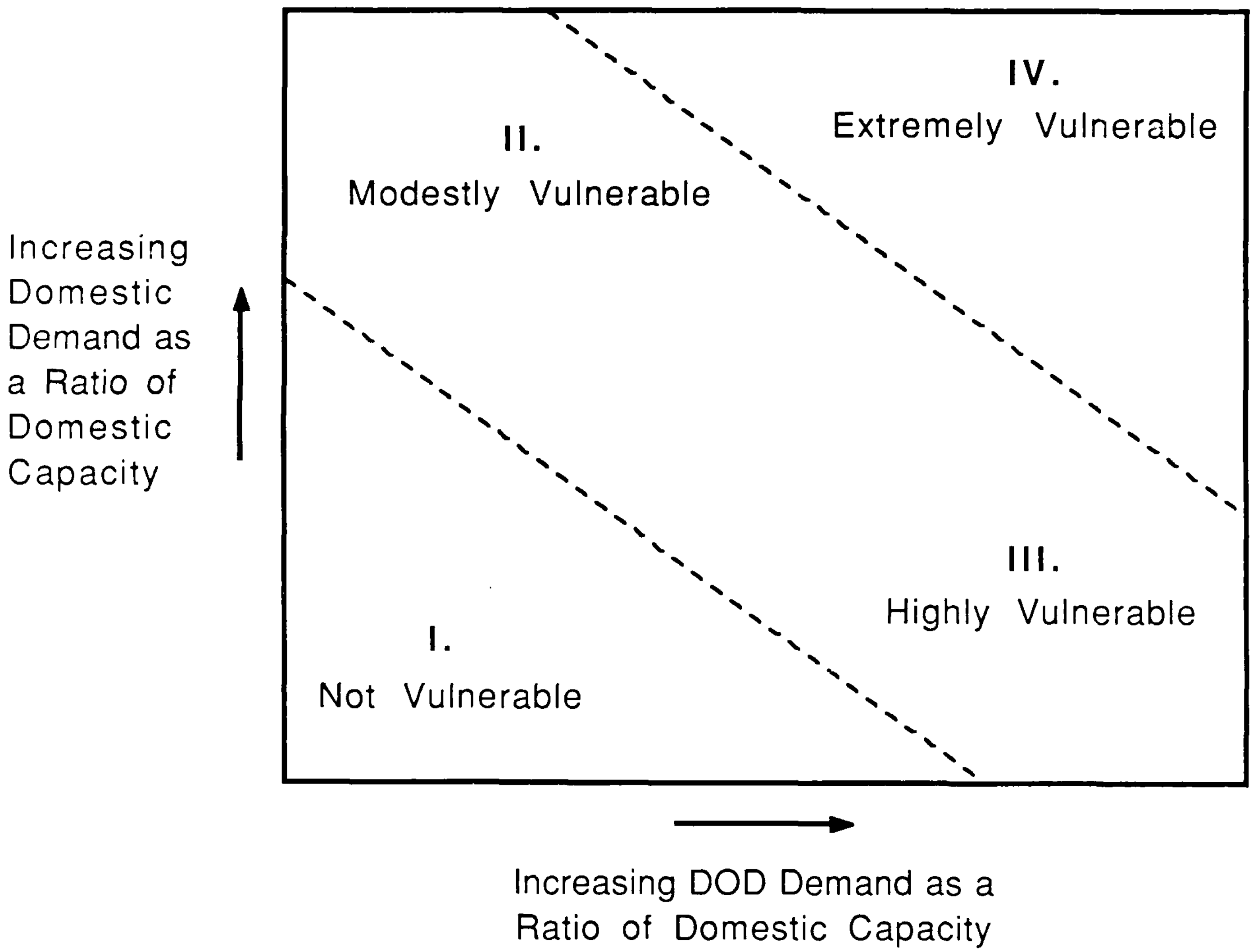


Figure 3-3

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Comparison of Critical or Strategic Materials

All Points: Peacetime Condition

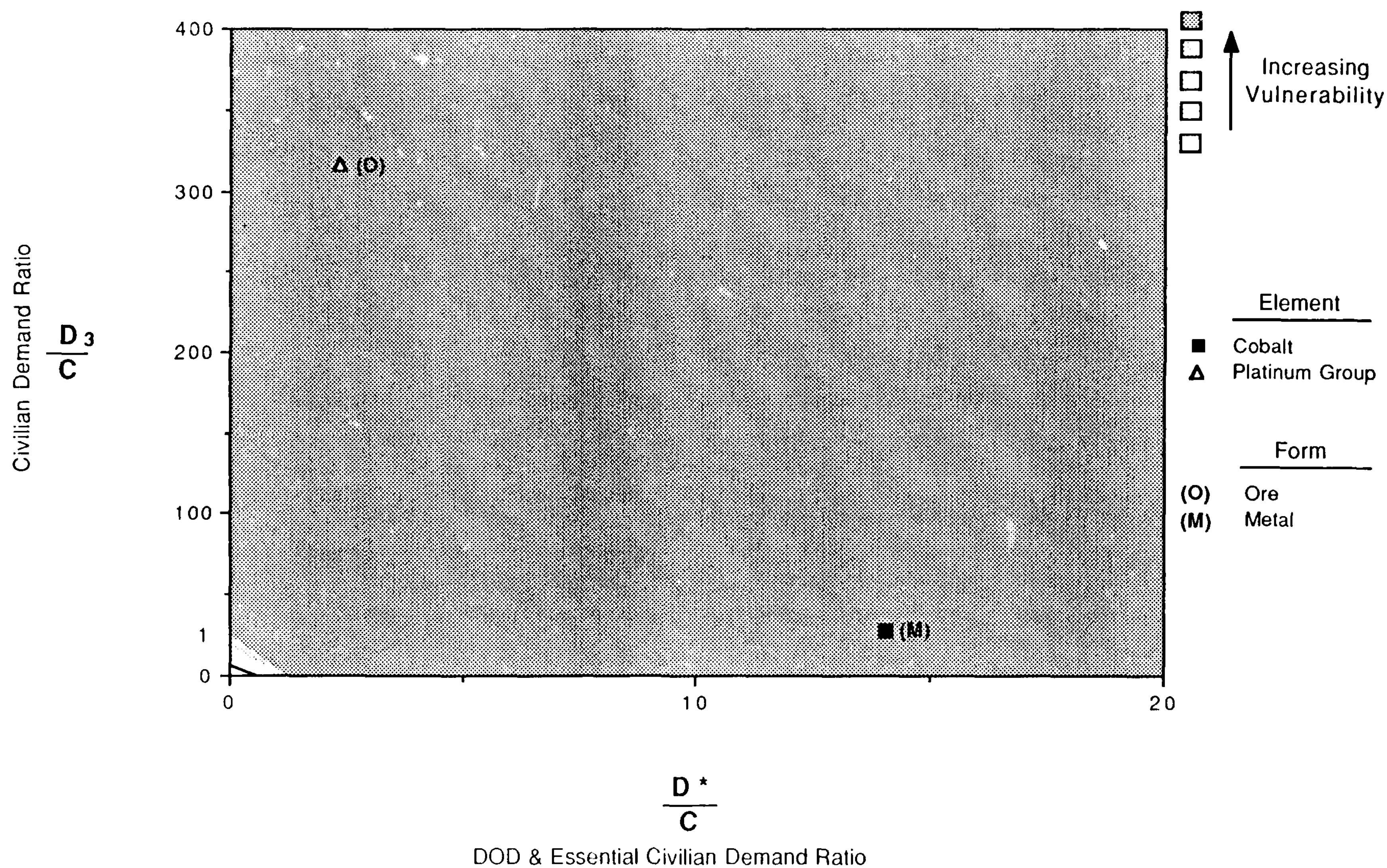


FIGURE 3-4

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Comparison of Critical or Strategic Materials

All Points: Peacetime Condition

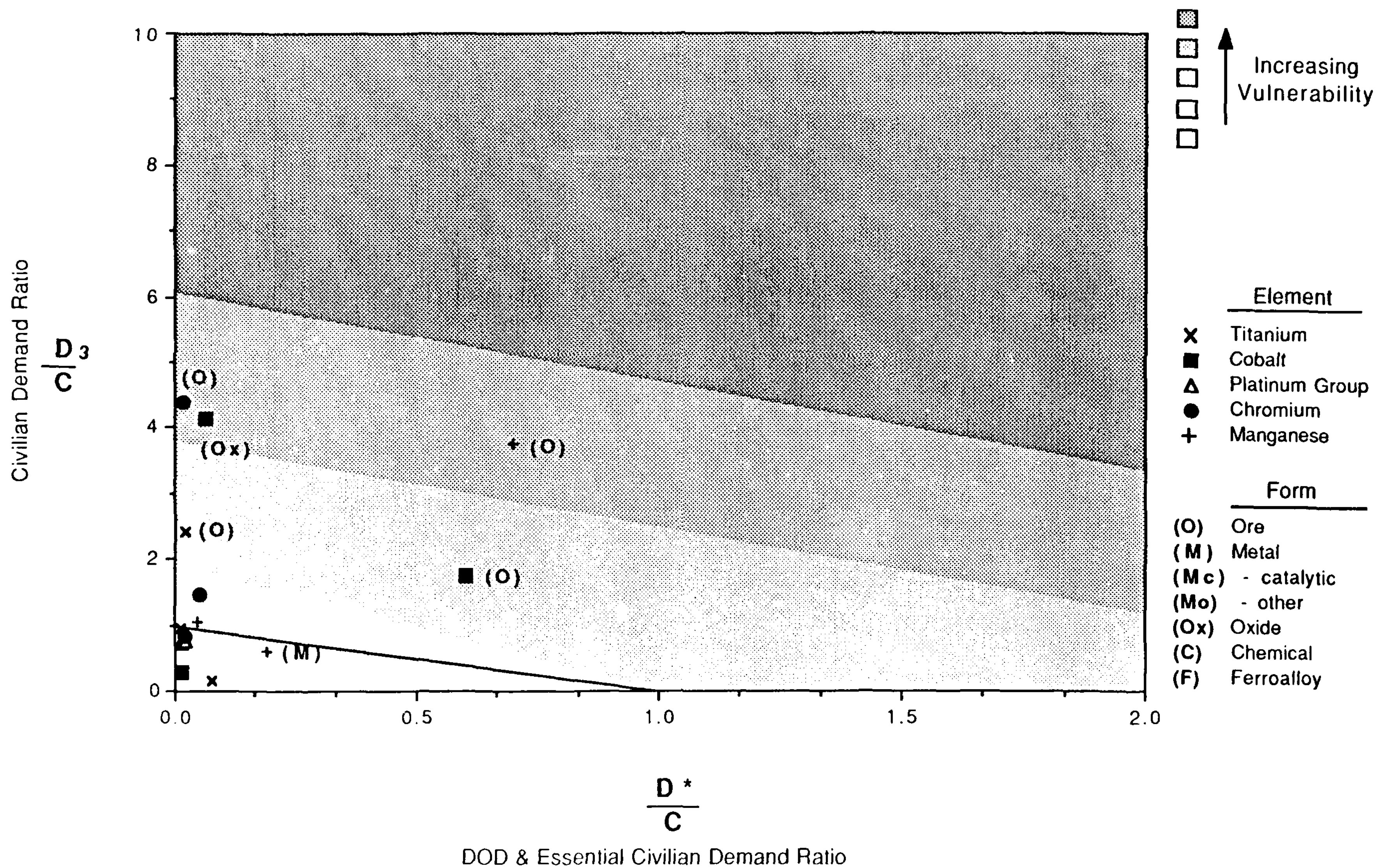
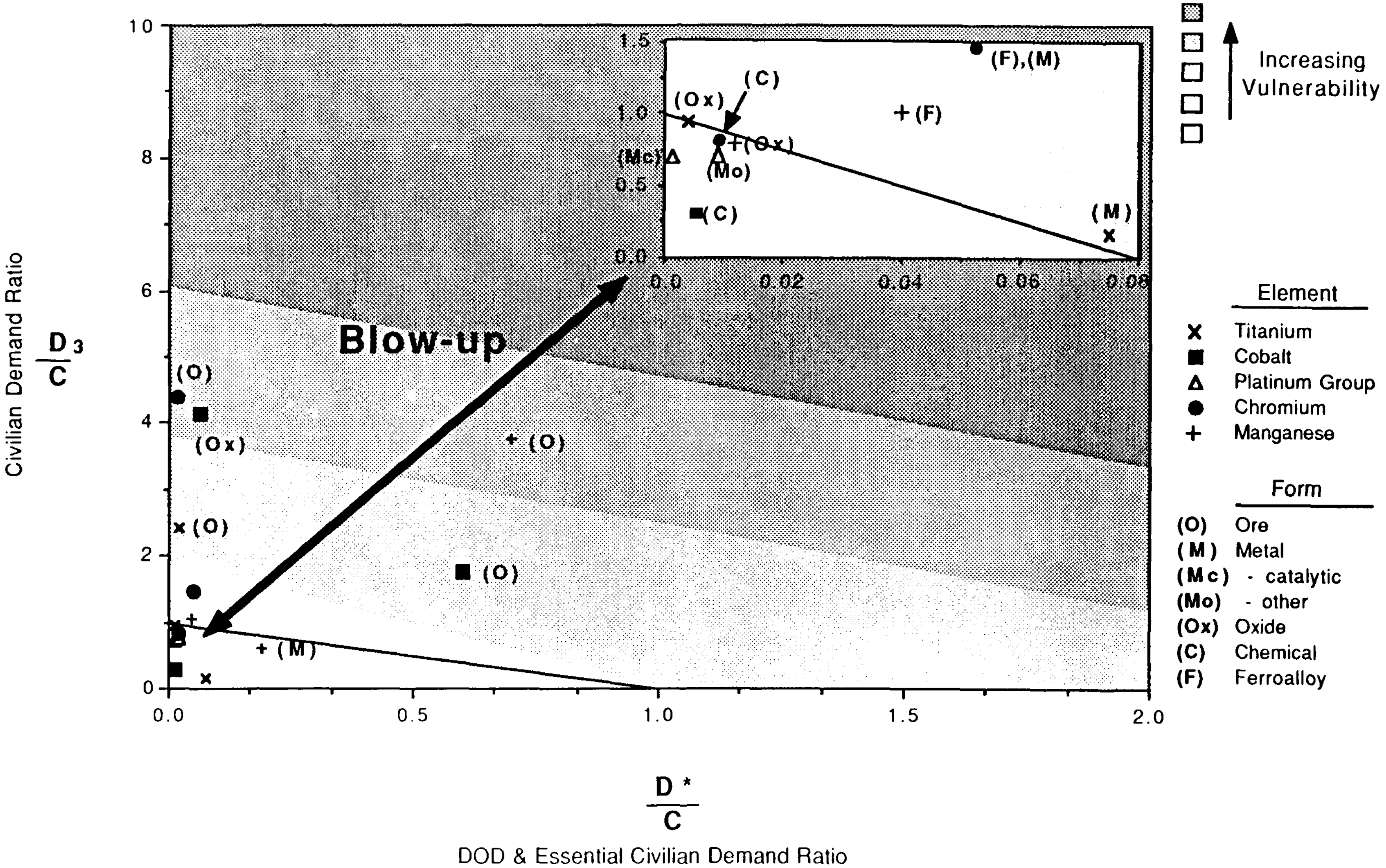


FIGURE 3-5

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Comparison of Critical or Strategic Materials

All Points: Peacetime Condition



potentially open to some question due to the use of only open source data and Arthur D. Little, Inc. estimates based on industry and government sources. However, the results indicated appear to be reasonable.

3.4 Capacity "Pinchpoint" Analysis

A further delineation of the flexibility of this methodology is evident in Table 3.1. A capacity "pinchpoint" threshold was arbitrarily set after the "VULNERABLE" region. Of the eighteen material/process/product form combinations evaluated, six (33%) of the total were analyzed to be past this capacity "pinchpoint" threshold. Not surprisingly, ore/mining of manganese, cobalt, and the platinum group metals were judged to be "extremely vulnerable." This is primarily due to the low grade, if any, domestic ore bodies and concomitant lack of economic incentives to tap these resources. In addition, because of small or negligible resources, there is also very limited domestic capacity for upgrading or benefication. In such cases, an upgraded form of the metal must be considered for stockpiling purposes. Interestingly, of all the materials studies, three out of four cobalt process/product forms had some degree of capacity vulnerability by this analysis. As it turns out, all of the materials to be evaluated in this study are materials where much, if not most, of the raw materials are imported:

	Estimated % of Foreign Supply
manganese	100
titanium	80
cobalt	100
chromium	100
platinum group	99+
rubber	99+

In addition, there has generally been a trend in recent years by resource bearing countries to vertically integrate into metal, chemical, and ferroalloy production for export, thereby maximizing profits.

Depending on the requirements of FEMA's analysis, the "pinchpoint" threshold can be shifted in either direction for different materials or forms (another approach can be to vary the region size or shape as dictated in Appendix C by changing the elasticity coefficients, etc.). This could also be used as a less graphic tool to "track" historical trends in commodity material/form capacity vulnerability.

A summary of product capacity "pinchpoints" for studied materials is shown in Table 3.2.

3.5 Capacity Implications to Overall Vulnerability

Given the capacity vulnerability analyses in the preceding sections, some general observations can be made regarding these materials when considering options such as stockpiling. These observations are solely based on estimated capacity vulnerability and not any historical trend data, analyses, or other equally critical issues. Strategic and critical

TABLE 3-1

CRITICAL OR STRATEGIC MATERIALS -
CAPACITY "PINCHPOINT" COMPARISON

INCREASING DEGREE OF VULNERABILITY

Example of Capacity "Pinchpoint" Threshold

Capacity Pinchpoint Exists

Material (element)	Product Form	Not Vulnerable	Slightly Vulnerable	Vulnerable	Very Vulnerable	Extremely Vulnerable
Manganese	Ore/Ben.Ore*					p 234
	Ferroalloys		P 234			
	Metals	P 2	34			
	Manganese Dioxide	P 234				
Titanium	Ore/Ben.Ore*			P 234		
	Metals	P 234				
	Titanium Dioxide	P 234				
Cobalt	Ore/Ben.Ore*			P	2	34
	Oxides				P 234	
	Chemicals (salts, etc.)	P 234				
	Metal				P 234	
Chromium	Ore/Ben.Ore*		P 234			
	Chemicals				P 234	
	Ferroalloys and Metal	P 234				
Platinum Group	Ore/Ben.Ore*					P 234
	Metal (catalytic)	P 234				
	Metals (other)	P 234				

P - Peacetime; 2 - Peacetime Demand;
3 - 3X Peacetime Demand; 4 - 4X Peacetime Demand
* Beneficiated Ore

TABLE 3-2

SUMMARY - CAPACITY "PINCHPOINTS"

Material (Element)	Product Form	Process
Manganese	Ore	Mining*
Titanium	Ore	Mining*
Cobalt	Ore Oxides Metal	Mining* Chemical Reduction
Chromium	Chemicals	Chemical
Platinum Group	Ore	Mining*
Natural Rubber	Rubber	Access to Rubber Bearing Trees

*includes benefication step

materials/forms studied that are judged to be high priority items are the same as shown in Table 3-2 based strictly on estimated capacity vulnerability.

3.6 Historical Trends

Finally, an example of the use of capacity vulnerability assessment plots to indicate historical trends is shown in Figure 3-6. Although this plot does not indicate that U.S. domestic ferroalloy production capacity is inadequate to meet domestic demand, it does indicate a trend in a vulnerable direction. The spacing between data points for equivalent time intervals indicates the rate of capacity vulnerability change. For ferroalloy production capacity, the slope of the change does appear to be increasing. To prepare a vulnerability assessment, existing production capacity for ferroalloys has been estimated to be around 2.19 million annual tons to be distributed amongst:

- ferro manganese,
- silicon manganese,
- ferro silicon,
- ferro chrome, and
- silicon metal.

Table 3-3 shows the breakdown in energy consumption for these various ferroalloys and silicon metal for a submerged arc furnace. This is a means by which furnace capacity can be rated. This does not apply to blast furnace capacity to produce ferroalloys.

3.7 Conclusion

A methodology has been developed to provide nonquantitative indicators of strategic materials vulnerabilty and where further effort may be warranted to assess the degree of vulnerability. The methodology has been applied to selected materials. Further refinements of the methodology may be warranted to estimate third and lower level flows to DOD in addition to secondary flows discussed above (see Appendix A for further details).

FIGURE 3-6

VULNERABILITY ASSESSMENT

Estimated Historical Trend For 1975-1985: Manganese, Chromium and Silicon Ferroalloys

All Points: Peacetime Condition

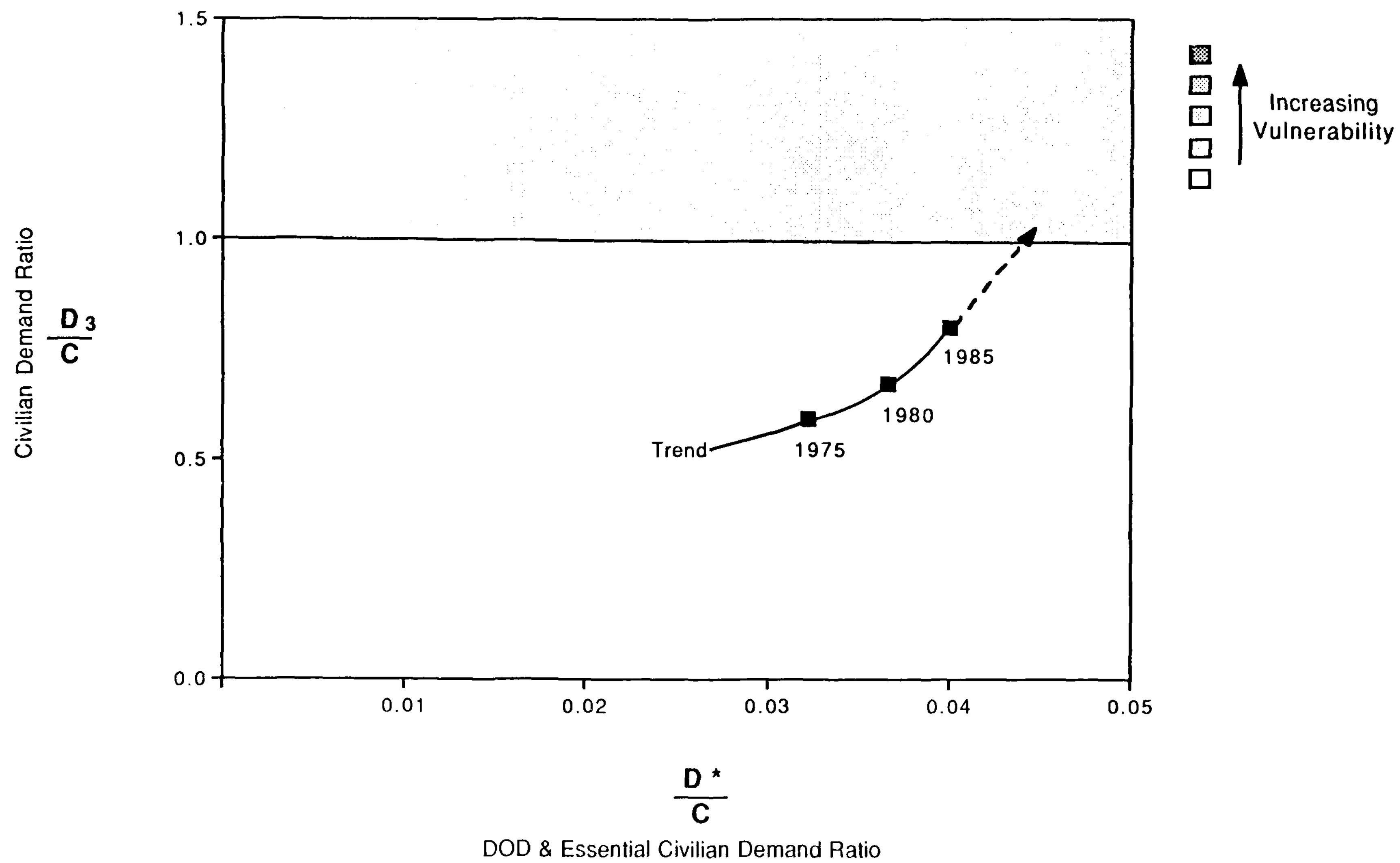


TABLE 3-3

ENERGY COMSUMPTION CONVERSIONS FOR FERRO ALLOYS

SUBMERGED ELECTRIC ARC FURNACES CAN BE CONVERTED WITH PROCESS CHANGES BETWEEN Fe Mn, SiMn AND FeCr FERRO ALLOYS ACCORDING TO APPROXIMATE ENERGY CONSUMPTION BELOW:

ELECTRIC ENERGY CONSUMPTION (KWH/net Ton)	ALLOY
2400	FeMn
4800	FeCr
8500	FeSi
14000	Si

Source: Arthur D. Little, inc. estimates based on internal and industry sources.

APPENDIX A

COMPUTATION OF DOD DEMAND FOR COBALT

Using publicly available information to estimate DOD dependency on strategic/critical materials, the methodology for tracking DOD dependency is based on:

1. Bureau of Mines information on tonnage flows of commodities to various SIC sectors - Table A-1.

2. Development of a relationship of SIC sectors to INFORUM economics sectors (see below).

3. INFORUM information on dollar flows between the various sectors (input/output) - Table A-2.

Figure A-1 shows the relationship of information from Bureau of Mines on commodity flows to INFORUM input/output information. Basically, Bureau of Mines showed consumption by SIC sector (in tons of a commodity). Inforum data for the SIC sector showed the dollars flow to DOD and to the civilian economy. If a civilian sector provided output to a DOD sector indirectly (i.e., as a middleman), it was called a "secondary to defense flow." In short, we assumed that tonnage flows of a commodity were proportional to the dollars flows. This was done by calculating a "commodity coefficient" (i.e., tons of commodity output per dollar of output) for each economic sector (i.e., transportation, machinery, chemicals, etc.).

Table A-2 is compiled from INFORUM economic sector data and U.S. Bureau of Mines tonnage flows to each economic sector. This table shows:

a. Total domestic output (tons) by sector;

b. Total domestic output (dollars) directly to defense;

c. Total domestic output (dollars)) directly to military construction;

d. Total domestic output (dollars) of secondary flows (indirect) to defense (e.g., aircraft engines sold to third parties who then sell to the defense sector);*

e. Total dollar flows to defense which is the sum of b, c, and d.

Our calculation of a commodity coefficient for each economic sector (e.g., transportation) is accomplished by dividing the SIC output for each economic sector in tons by the total dollar flow in millions of dollars to obtain a coefficient. For example, for cobalt to transportation sector from Tables A1 and A2, one can calculate:

$$\frac{\text{3697 tons cobalt to transportation}}{\$42{,}278.7} = 0.0874 \text{ tons/million dollar for transportation sector}$$

*See discussion on Page A-7 for tertiary and lower level flows.

TABLE A-1: DOMESTIC COBALT DEMAND ESTIMATES

	SIC	Total Cobalt* (tons)
Transportation	372,376	3,697
Electrical	2,375	843
Machinery	2,259	778
Paints	2,851	1,312
Chemicals	1,552	762
Other	--	801
TOTAL		8,193

*Source: BuMines: Mineral Facts and Problems

TABLE A-2: COBALT DEMAND

		D_1		D_2		D*
	Total Domestic Output ($ Million)	Direct to Defense ($ Million)	Direct to Military Construction ($ Million)	Secondary to Defense ($ Million)	Total to Defense ($ Million)	Co to Defense (tons)
Transportation (subtotal)	42,278.7	22,211.8	0	49.63	22,261.43	1,946
Aircraft	18,979.2	11,172.1		5.65		
Aircraft, missile engines, ENG	8,846.1	4,335.7		15.48		
Aircraft, missile equipment, NEC	7,395	1,963.4		28.5		
Complete guided missiles	7,058.4	4,740.6		0		
Electrical (subtotal)	134,306.4	15,351.7	57	919.33	16,328.03	102.4
Transformers	2,556.8	28.8		24.36		
Switchgear and switchboard apparatus	4,590.3	49.3	18.8	20.98		
Motors and generators	6,044.8	215.7		46.63		
Industrial controls	3,766.3	76		51.8		
Welding apparatus	1,725.1	10.3		55.6		
Carbon and graphite products	1,002.7	8.2		1.58		
Electrical industrial, appliance, NEC	885.2	8.2		5.01		
HHLD cooking equipment	2,009.5	0		.05		
HHLD refrigerators and freezers	2,109	1.8		0		
HHLD laundry equipment	1,873.8	0		.24		
Electric housewares and fans	3,078	3.7		.24		
HHLD vacuum cleaners	853.4	0		.08		
Sewing machines	161	0		1.92		
Household appliances, NEC	1,612.6	7.4		.51		
Electric lamps	4,373.4	12.7	20.5	5.6		
Lighting fixtures and equipment	3,791.4	25.5	14.2	13.05		
Wiring devices	4,071.9	34		27.53		
Radio and TV receiving sets	4,939.7	49.2		5.49		
Electron tubes	1,457.6	284.3		1.51		
Semi conductors and related	15,081.7	414.8		330.16		
Electric components, NEC	13,908.9	420.6		96.13		

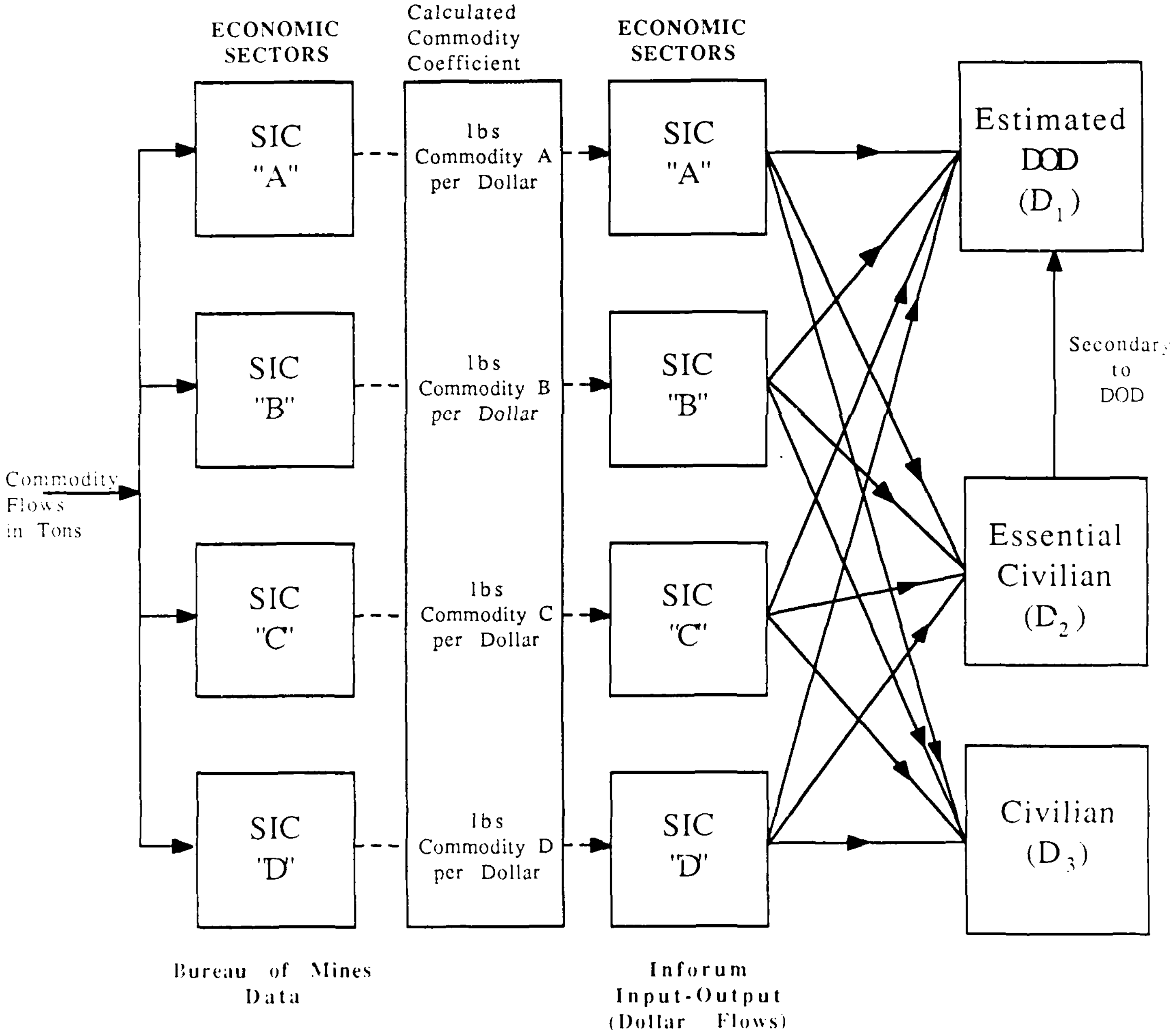
TABLE A-2: COBALT DEMAND (CONTINUED)

	Total Domestic Output ($ Million)	D_1: Direct to Defense ($ Million)	D_1: Direct to Military Construction ($ Million)	D_2: Secondary to Defense ($ Million)	Total to Defense ($ Million)	D^*: Co to Defense (tons)
Storage batteries	2,300.7	108.3		8.20		
Primary batteries, dry and wet	2,905.4	61.6		.93		
X-ray apparatus and tubes	2,491.6	14.9		4.14		
Engine electrical equipment	3,131.1	42.5		19.82		
Electrical equipment	880.7	4.2		.92		
Machinery	43,005.8	459.7	12.8	400.83	873.33	15.8
Construction	19,895.9	126.9	4.2	201.53		
Mining	2,773.7	1.9		74.85		
Oil field (modify for defense)	5,379.2	0		0		
Elevators and escalators	643.1	3.9	4.6	6.69		
Conveyors	2,044.8	11.6	4	14.07		
Hoists, cranes, mono-rails	1,197.3	5.8		29.37		
Trucks and tractors (industrial)	2,573.5	23.2		1.06		
Special dies, tools, machine tools	8,498.3	286.4		73.26		
Paints	6,511.8	55		87.18	142.18	28.6
Chemicals	47,943.9	657.4		211.01	868.41	13.8
More electrical*						
Phonograph records, tapes	1,457.6	3.8		.06		
Telephone and telegraph	15,081.7	216.2		22.97		
Radio and TV communication	26,183.5	13,249.7	3.5	178.86		

* Included in Total Electrical

FIGURE A-1

Relationship of Bureau of Mines Commodity data to Inforum Input-Output Information



This coefficient is used to calculate cobalt output in tons for Items b,c, and d above to provide:

- Estimated direct cobalt demand by defense (DOD) (D_1) in tons per year.

- Estimated secondary cobalt demand by defense (DOD) in tons, referred to as essential civilian demand (D_2), and

- Estimated civilian demand (D_3) for cobalt the transportation economic sector.

This process is duplicated for each SIC economic sector (i.e., determine commodity coefficient and convert dollar flows to ton flows).

Similar tables for manganese (Table A-3), chromium (Table A-4), titanium (Table A-5), and platinum group (Table A-6) are at the end of this appendix.

The above approach was selected since the information is: 1) in the non-classified public domain; and 2) readily accessible.

For most cases, only secondary flows were determined from INFORUM data since it was found that primary and secondary flows accounted for more than an estimated 90% of the total. However, there are cases where a third or fourth level flow may be important and is a potential area for further investigation. One example of where such judgment was used was in tracking cobalt flows to oil drilling equipment "oil field machinery" and to oil field extraction. At this level of detail, there is no indication of a defense need for oil - only by going to one further level of detail to "petroleum refining" does one find purchases by the defense sector of 3.64% of petroleum products (excluding fuels) and 5.90% of fuel oil products for a weighted average of 4.1%. As an approximation, this weighted average can be used to obtain an estimate of indirect DOD demand on "oil field machinery.

- Thirty-six percent was accounted for by net exports according to INFORUM data, with the difference accounted for by domestic consumers accounting to $3,443 million ($5,379 (1-0.36)).

- Indirect DOD demand is assumed to be 4.1% of this amount or $141 million.

- Thus, total cobalt to defense in the category of machinery is then 26.6 tons (22.9 x 873.33 +K 141/873.33). This value would have to be added to Table A-4.

TABLE A-3: MANGANESE DEMAND

conomic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Construction	95076.8	896.65	1413.12	546.0	2855.8
New Construction	73897.3	0.0	1043.8	0.0	1043.8
abricated Structural Metal	3877.1	214.2	78.9	240.5	533.6
etal Doors, Sash, Trim	2052.3	14.5	32.2	52.7	99.4
oiler Shops	7109.2	551.9	108.2	130.5	790.6
Sheet Metal Work	4825.6	50.8	57.7	71.0	179.5
Architectural Metal Work	649.1	7.3	18.8	51.3	77.4
refabricated Metal Buildings	1496.8	39.9	27.0	0.0	66.9
iscellaneous Metal Work	1169.4	18.1	46.5	0.0	64.6
Transportation	187935.4	19828.9	0.0	250.2	20079.1
ruck & Bus Bodies	5252.0	0.0	0.0	9.8	9.8
ruck Trailers	3409.0	14.3	0.0	0.1	14.4
otor Vehicles	74858.0	357.3	0.0	0.0	357.3
Motor Vehicle Parts and Accesories	37994.7	80.0	0.0	166.8	246.8
Aircraft	18979.2	7727.7	0.0	0.0	7727.7
ircraft Missile Engines, ENG	8846.1	2999.0	0.0	0.1	2999.1
ircraft, Missile Equipment, NEC	7395.0	1358.1	0.0	0.1	1358.2
Complete Guided Missiles	7058.4	3279.1	0.0	0.0	3279.1
Ship Building and Repairing	9010.7	3781.7	0.0	50.8	3832.5
oat Building and Repairing	2366.9	25.4	0.0	0.0	25.4
ailroad Equipment	5355.7	198.1	0.0	5.7	203.8
otorcycles, Bicycles and Parts	2464.9	8.2	0.0	9.0	17.2
Travel Trailers and Campers	678.2	0.0	0.0	0.0	0.0
Mobile Homes	3891.1	0.0	0.0	0.0	0.0
ansportation Equipment, NEC	375.5	0.0	0.0	7.8	7.8
Machinery	176425.3	961.0	14.6	1474.6	2450.2
Steam Engines and Turbines	2963.2	61.7	0.0	49.3	111.0
ternal Combustion Engines	9942.6	173.8	0.0	123.6	297.4
rm Machinery and Equipment	14109	6.6	0.0	12.7	19.3
wn and Garden Equipment	2206.8	0.0	0.0	7.7	7.7
Construction Machinery and Equipment	19895.9	64.5	2.1	48.7	115.3
Mining Machinery	2773.7	1.0	0.0	0.0	1.0
l Field Machinery	5739.2	0.0	0.0	0.0	0.0
evators and Moving Stairways	643.1	2.0	0.0	3.4	5.4
Conveyors and Conveying Equipment	2044.8	5.9	2.0	2.0	9.9
Hoists,Cranes, Monorails	1197.3	3.0	0.0	14.0	17.0
dustrial Trucks and Tractors	2573.5	11.8	0.0	1.1	13.0
chine Tools and Metal Cutting	3149.6	11.8	0.0	12.0	23.8
achine Tools and Metal Forming	980.9	3.9	0.0	6.1	10.0
Special Dies, Machine Tool	8498.3	17.7	0.0	109.9	127.6
ower Driven Hand Tools	2468.3	4.9	0.0	4.0	8.9
lling Mill Machinery	448.8	0.0	0.0	0.0	0.0
talworking Machinery	1311.1	4.9	0.0	3.1	8.0
Textile Machinery	775.1	0.0	0.0	0.2	0.2
Woodworking Machinery	688.9	0.9	0.0	0.1	1.0
per Industries Machinery	549.4	0.9	0.0	0.3	1.2
inting Trades Machinery	260.5	2.8	0.0	0.1	2.9
pec Industrial Machinery, NEC	3389.3	16.0	0.0	15.0	31.0
Pumps and Compressors	7540.4	48.3	0.0	92.6	140.9
ll and Roller Bearings	2784.0	27.6	0.0	51.1	78.7
owers and Fans	1624.8	7.9	6.1	2.4	16.4
dustrial Patterns	452.5	0.0	0.0	1.1	1.1

TABLE A-3: MANGANESE DEMAND (Continued)

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Power Transmission Equipment	3376.3	3.0	0.0	50.5	53.4
Industrial Furnaces and Ovens	767.9	1.0	0.0	0.1	1.1
General Industrial Machinery, NEC	3316.1	20.7	0.0	16.1	36.8
Carberators, Pistons, Rings, Valves	1362.1	1.0	0.0	9.3	10.3
Non Elec Mach, NEC	13100.8	41.4	0.0	767.3	808.7
Electronic Computing Equipment	34829.3	363.2	0.0	34.6	397.8
Calc and Accounting Machines	2084.5	5.8	0.0	0.1	5.8
Typewriters	1095.3	3.0	0.0	3.4	6.4
Scales and Balances	582.8	1.0	0.0	0.3	1.3
Office Machines, NEC	480.3	15.2	0.0	2.2	17.3
Automatic Merchandising Machines	432	0.0	0.0	0.1	0.1
Commercial Laundry Equipment	241.6	1.0	0.0	0.1	1.0
Refrig and Heating Equip	10706.6	24.1	0.0	20.8	44.9
Measur and Dispens Pumps	288.3	0.0	0.0	0.0	0.0
Service Ind Machines	2800.1	1.9	4.4	9.3	15.6
Food Products Machines	1950.3	0.9	0.0	0.2	1.1
Cans and Containers	9094.9	37.9	0.0	98.6	136.6
Metal Cans	8191.2	7.6	0.0	37.9	45.5
Metal Barrells, Drums, Pails	903.7	30.3	0.0	60.7	91.0
Appliances and Equipment	19629.6	170.6	16.2	314.5	501.4
Cutlery	619.4	4.1	0.0	7.7	11.8
Hand and Edge Tools, NEC	1742.2	94.3	3.4	40.7	138.4
Hand Saws and Saw Blades	483.2	0.0	0.0	17.5	17.5
Hardware, NEC	5087.5	49.2	12.8	248.6	310.6
HHLD Cooking Equipment	2009.5	0.0	0.0	0.0	0.0
HHLD Refrigerators and Freezers	2109.0	3.2	0.0	0.0	3.2
HHLD Laundry Equipment	1873.8	0.0	0.0	0.0	0.0
Electric Housewares and Fans	3078.0	6.6	0.0	0.0	6.6
HHLD Vacuum Cleaners	853.4	0.0	0.0	0.0	0.0
Sewing Machines	161.0	0.0	0.0	0.2	0.2
Household Appliances, NEC	1612.6	13.2	0.0	0.0	13.2
Oil and Gas Industries	56258.0	33.3	0.0	1159.1	1192.4
Crude Oil Extraction	32917.0	0.0	0.0	1032.1	1032.1
Natural Gas Extraction	19532.7	0.0	0.0	72.0	72.0
Pipelines	3808.3	33.3	0.0	55.0	88.3
Chemicals	134456.3	232.3	0.6	61.9	294.9
Industrial Chemls (Inorg & Org)	47943.9	107.6	0.0	1.1	108.7
Fertilizers, Nitrog & Phosphate	9051.9	0.5	0.0	4.7	5.2
Fertilizers, Mixing Only	1316.4	0.0	0.0	0.1	0.1
Agricultural Chemicals, NEC	3413.8	0.5	0.0	2.5	3.0
Gum and Wood Chemicals	425.6	0.0	0.0	0.5	0.5
Adhesives and Sealants	2703.3	1.4	0.6	1.0	3.1
Explosives	956.0	55.9	0.0	6.5	62.4
Printing Ink	1270.2	0.0	0.0	0.7	0.7
Carbon Black	572.9	0.0	0.0	0.4	0.4
Chemical Preparations, NEC	4633.4	20.8	0.0	6.0	26.8
Plastic Materials and Resins	17549.9	4.3	0.0	24.1	28.4
Synthetic Rubber	3261.9	0.7	0.0	3.8	4.5
Cellulosic Man-Made Fibers	1133.7	2.9	0.0	0.2	3.1
Noncellulosic Fibers	6342.8	5.7	0.0	0.5	6.2
Drugs	14612.4	15.9	0.0	1.5	17.4
Soap and Other Detergents	2914.4	2.6	0.0	2.9	5.5
Polishes and Sanitation Goods	1673.7	2.4	0.0	3.0	5.4
Surface Active Agents	1361.6	2.1	0.0	2.2	4.3
Toilet Preparations	6806.7	0.2	0.0	0.1	0.3

TABLE A-3: MANGANESE DEMAND (Continued)

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Paints and Allied Products	6511.8	9.0	0.0	0.0	9.0
Batteries	2905.4	530.0	0.0	0.86	530.9

TABLE A-4: CHROMIUM DEMAND

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Chemical	134456.3	655.0	1.8	174.6	831.3
Industrial Chemicals (Inorg & Org)	47943.9	303.2	0.0	3.0	306.2
Fertilizers, Nitrog & Phosphate	9051.9	1.3	0.0	13.3	14.7
Fertilizers, Mixing Only	1316.4	0.0	0.0	0.2	0.2
Agricultural Chemicals, NEC	3413.8	1.3	0.0	7.0	8.3
Gum and Wood Chemicals	425.6	0.0	0.0	1.4	1.4
Adhesives and Sealants	2703.3	4.0	1.8	2.9	8.7
Explosives	956.0	157.6	0.0	18.4	176.0
Printing Ink	1270.2	0.0	0.0	2.1	2.1
Carbon Black	572.9	0.0	0.0	1.3	1.3
Chemical Preparations, NEC	4633.4	58.8	0.0	16.8	75.6
Plastics Materials and Resins	17549.9	12.0	0.0	67.9	79.9
Synthetic Rubber	3261.9	2.0	0.0	10.7	12.7
Cellulosic Man-Made Fibers	1133.7	8.0	0.0	0.7	8.7
Noncellulosic Fibers	6342.8	16.0	0.0	1.4	17.4
Drugs	14612.4	44.7	0.0	4.2	49.0
Soap & Other Detergents	2914.4	7.3	0.0	8.1	15.5
Polishes and Sanitation Goods	1673.7	6.7	0.0	8.4	15.1
Surface Active Agents	1361.6	6.0	0.0	6.1	12.1
Toilet Preparations	6806.7	0.6	0.0	0.4	1.1
Paints and Allied Products	6511.8	25.4	0.0	0.1	25.4
Refactory (Nonclay)	853.7	0.0	0.0	43.1	43.1
Fabricated Metal Products	88121.2	1063.3	72.4	530.3	1666.0
Metal Cans	8191.2	0.6	0.0	2.8	3.4
Metal Barrells, Drums, Pails	903.7	2.2	0.0	4.5	6.7
Metal Sanitary Ware	256.4	0.0	0.3	0.4	0.7
Plumbing Fixtures	1002.7	2.2	0.9	1.5	4.6
Heating Equipment, Exc Elec	1274.6	6.7	1.9	1.2	9.9
Fabricated Structural Metal	3877.1	33.2	12.2	37.3	82.7
Metal Doors, Sash, Trim	2052.3	2.2	5.0	8.2	15.4
Boiler Shops	7109.2	85.5	16.8	20.2	122.4
Sheet Metal Work	4825.6	7.9	8.9	11.0	27.8
Architectural Metal Work	649.1	1.1	2.9	8.0	12.0
Prefabricated Metal Buildings	1496.8	6.2	4.2	0.0	10.4
Miscellaneous Metal Work	1169.4	2.8	7.2	0.0	10.0
Screw Machine Products,Bolts,Nuts	4920.5	21.9	0.0	66.5	88.5
Auto Stampings	8679.9	0.6	0.0	11.7	12.3
Crowns and Closures	525.3	0.0	0.0	0.2	0.2
Metal Stampings, NEC	5333.4	1.7	0.0	32.5	34.2
Cutlery	619.4	0.6	0.0	1.1	1.6
Hand and Edge Tools, NEC	1742.2	12.9	0.5	5.6	19.0
Hand Saws and Saw Blades	483.2	0.0	0.0	2.4	2.4
Hardware, NEC	5087.5	6.7	1.8	34.1	42.6
Plating and Polishing	2380.4	6.2	0.0	43.3	49.5
Metal Coating and Allied Service	2162.4	5.1	0.0	28.4	33.5
Misc. Fabricated Wire Product	3211.7	5.6	0.0	12.9	18.5
Steel Springs, Exc Wire	384.6	0.0	0.0	1.3	1.3
Pipe, Valves, Pipe Fittings	7870.6	39.9	9.6	38.7	88.2
Metal Foil and Leaf	1115.4	0.6	0.0	0.5	1.1
Fabricated Metal Product, NEC	4527.5	10.1	0.4	155.1	165.6
Tanks	3581.7	512.8	0.0	0	512.8
Small Arms	1017.8	23.6	0.0	0	23.6
Small Arms Ammunition	781.8	84.9	0.0	0	84.9
Other Ordnance & Accessories	887.8	179.4	0.0	1.0	180.4

TABLE A-4: CHROMIUM DEMAND (Continued)

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Machinery	313279.8	1778.1	8.7	313.1	2099.9
Steam Engines and Turbines	2963.2	12.3	0.0	9.8	22.1
Internal Combustion Engines	9942.6	34.6	0.0	24.6	59.3
Farm Machinery and Equipment	14109.0	1.3	0.0	2.5	3.8
Lawn and Garden Equipment	2206.8	0.0	0.0	1.5	1.5
Construction Machinery and Equipment	19895.9	12.8	0.4	9.7	23.0
Mining Machinery	2773.7	0.2	0.0	0.0	0.2
Oil Field Machinery	5739.2	0.0	0.0	0.0	0.0
Elevators and Moving Stairways	643.1	0.4	0.0	0.7	1.1
Conveyors and Conveying Equipment	2044.8	1.2	0.4	0.4	2.0
Hoists, Cranes, Monorails	1197.3	0.6	0.0	2.8	3.4
Industrial Trucks and Tractors	2573.5	2.4	0.0	0.2	2.6
Machine Tools & Metal Cutting	3149.6	2.3	0.0	2.4	4.7
Machine Tools & Metal Forming	980.9	0.8	0.0	1.2	2.0
Special Dies, Machine Tool	8498.3	3.5	0.0	21.9	4.3
Power Driven Hand Tools	2468.3	1.0	0.0	0.8	1.0
Rolling Mill Machinery	448.8	0.0	0.0	0.0	0.6
Metalworking Machinery	1311.1	1.0	0.0	0.6	1.0
Textile Machinery	775.1	0.0	0.0	0.0	0.0
Woodworking Machinery	688.9	0.2	0.0	0.0	0.2
Paper Industries Machinery	549.4	0.2	0.0	0.0	0.2
Printing Trades Machinery	260.5	0.6	0.0	0.0	0.6
Spec Industrial Machinery, NEC	3389.3	3.2	0.0	3.0	6.2
Pumps and Compressors	7540.4	9.6	0.0	18.5	28.1
Ball and Roller Bearings	2784.0	5.5	0.0	10.2	15.7
Blowers and Fans	1624.8	1.6	1.2	0.5	3.3
Industrial Patterns	452.5	0.0	0.0	0.2	0.2
Power Transmission Equipment	3376.3	0.6	0.0	10.1	10.6
Industrial Furnaces and Ovens	767.9	0.2	0.0	0.0	0.2
General Industrial Machinery, NEC	3316.1	4.1	0.0	3.2	7.3
Carberators, Pistons, Rings, Valves	1362.1	0.2	0.0	1.8	2.0
Non Elec Machinery, NEC	13100.8	8.3	0.0	152.9	161.1
Electronic Computing Equipment	34829.3	72.4	0.0	6.9	79.3
Calc and Accounting Machines	2084.5	1.1	0.0	0.0	1.2
Typewriters	1095.3	0.6	0.0	0.7	1.3
Scales and Balances	582.8	0.2	0.0	0.1	0.3
Office Machines, NEC	480.3	3.0	0.0	0.4	3.5
Automatic Merchandising Machines	432.0	0.0	0.0	0.0	0.0
Commercial Laundry Equipment	241.6	0.2	0.0	0.0	0.2
Refrig and Heating Equip	10706.6	4.8	0.0	4.1	9.0
Measur & Dispens Pumps	288.3	0.0	0.0	0.0	0.0
Service Ind Machines	2800.1	0.4	0.9	1.9	3.1
Food Products Machinery	1950.3	0.2	0	0.0	0.2
Instruments to Measure Elec	2629.1	26.1	0.0	14.0	40.1
Transformers	2556.8	2.9	0.0	0.1	3.1
Switchgear and Switchboard Apparatus	4590.3	5.0	1.9	0.1	7.0
Motors and Generators	6044.8	21.9	0.0	0.3	22.2
Industrial Controls	3766.3	7.7	0.0	0.3	8.0
Welding Apparatus	1725.1	1.0	0.0	0.3	1.4
Carbon and Graphite Products	1002.7	0.8	0.0	0.0	0.8
Electrical, Industrial Appliance, NEC	885.2	0.8	0.0	0.0	0.9
HHLD Cooking Equipment	2009.5	0.0	0.0	0.0	0.0
HHLD Refrigerators and Freezers	2109	0.2	0.0	0.0	0.2
HHLD Laundry Equipment	1873.8	0.0	0.0	0.0	0.0
Electric Housewares and Fans	3078	0.4	0.0	0.0	0.4
HHLD Vacuum Cleaners	853.4	0.0	0.0	0.0	0.0
Sewing Machines	161	0.0	0.0	0.0	0.0
Household Appliances, NEC	1612.6	0.8	0.0	0.0	0.8
Electric Lamps	4373.4	1.3	2.1	0.0	3.4
Lighting Fixtures and Equipment	3791.4	2.6	1.4	0.1	4.1
Wiring Devices	4071.9	3.5	0.0	0.2	3.6

TABLE A-4: CHROMIUM DEMAND (Continued)

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Radio and TV Receiving Sets	4939.7	5.0	0.0	0.0	5.0
Electron Tubes	1457.6	28.9	0.0	0.0	28.9
Semi-Conductors	15081.7	42.2	0.0	1.9	44.1
Electric Components, NEC	13808.9	42.8	0.0	0.6	43.3
Storage Batteries	2300.7	11.0	0.0	0.0	11.1
Primary Batteries, Dry and Wet	2905.4	6.3	0.0	0.0	6.3
X-Ray Apparatus and Tubes	2491.6	1.5	0.0	0.0	1.5
Engine Electrical Equipment	3131.1	4.3	0.0	0.1	4.4
Electrical Equipment	880.7	0.4	0.0	0.0	0.4
Phonograph Records, Tapes	1457.6	0.4	0.0	0.0	0.4
Telephone and Telegraph	15081.7	22.0	0.0	0.1	22.1
Radio and TV Communication Eq	26183.5	1346.8	0.4	1.0	1348.2
Transportation	187935.4	5948.4	0.0	75.1	6023.5
Truck & Bus Bodies	5252.0	0.0	0.0	2.9	2.9
Truck Trailers	3409	4.3	0.0	0.0	4.3
Motor Vehicles	74858	107.2	0.0	0.0	107.2
Motor Vehicle Parts and Accessories	37994.7	24.0	0.0	50.1	74.1
Aircraft	18979.2	2318.2	0.0	0.0	2318.2
Aircraft, Missile Engines, ENG	8846.1	899.7	0.0	0.0	899.7
Aircraft, Missile Equipment, NEC	7395	407.4	0.0	0.0	407.5
Complete Guided Missiles	7058.4	983.7	0.0	0.0	983.7
Ship Building and Repairing	9010.7	1134.5	0.0	15.3	1149.7
Boat Building and Repairing	2366.9	7.6	0.0	0.0	7.6
Railroad Equipment	5355.7	59.4	0.0	1.7	61.2
Motorcycles, Bicyccles & Pts	2464.9	2.4	0.0	2.7	5.1
Travel Trailers & Campers	678.2	0.0	0.0	0.0	0.0
Mobile Homes	3891.1	0.0	0.0	0.0	0.0
Transportation Equipment, NEC	375.5	0.0	0.0	2.3	2.3

TABLE A-5: TITANIUM DEMAND

Economic Sector	Total Domestic Output (Million$)	D1: Direct to Defense (Tons)	D1: Direct to Military Construction (Tons)	D2: Secondary to Defense (Tons)	D*: Total to Defense (Tons)
Aircraft	18979.2	2354.5	0.0	0.0	2354.5
Industrial Equipment	88121.2	98.8	6.7	52.3	157.9
Metal Cans	8191.2	0.1	0.0	0.3	0.3
Metal Barrells, Drums, Pails	903.7	0.2	0.0	0.4	0.6
Metal Sanitary Ware	256.4	0.0	0.0	0.0	0.1
Plumbing Fixtures	1002.7	0.2	0.1	0.1	0.4
Heating Equipment, Exc Elec	1274.6	0.6	0.2	0.1	0.9
Fabricated Structural Metal	3877.1	3.1	1.1	3.5	7.7
Metal Doors, Sash, Trim	2052.3	0.2	0.5	0.8	1.4
Boiler Shops	7109.2	7.9	1.6	1.9	11.4
Sheet Metal Work	4825.6	0.7	0.3	4.1	5.6
Architectural Metal Work	649.1	0.1	0.3	0.7	1.1
Prefabricated Metal Buildings	1496.8	0.6	0.4	0.0	1.0
Miscellaneous Metal Work	1169.4	0.3	0.7	0.0	0.9
Screw Machine Products, Bolts, Nuts	4920.5	2.0	0.0	6.2	3.2
Auto Stampings	3679.9	0.1	0.0	1.1	1.2
Crowns and Closures	525.3	0.0	0.0	0.0	0.0
Metal Stampings, NEC	5333.4	0.2	0.0	3.0	3.2
Cutlery	619.4	0.1	0.0	0.1	0.2
Hand and Edge Tools, NEC	1742.2	1.2	0.0	0.5	1.3
Hand Saws and Saw Blades	483.2	0.0	0.0	0.2	0.2
Hardware, NEC	5087.5	0.6	0.2	3.2	3.9
Plating and Polishing	2380.4	0.6	0.0	4.0	4.6
Metal Coating and Allied Service	2162.4	0.5	0.0	2.6	3.1
Misc. Fabricated Wire Product	3211.7	0.5	0.0	1.2	1.7
Steel Springs, Exc Wire	384.6	0.0	0.0	0.1	0.1
Pipe, Valves, Pipe Fittings	7870.6	3.7	0.9	3.6	8.2
Metal Foil and Leaf	1115.4	0.1	0.0	0.0	0.1
Fabricated Metal Product, NEC	4527.5	0.9	0.0	14.4	15.4
Tanks	3581.7	47.6	0.0	0	47.6
Small Arms	1017.8	2.2	0.0	0	2.2
Small Arms Ammunition	781.8	7.9	0.0	0	7.9
Other Ordnance & Accessories	887.8	16.7	0.0	0.1	16.8
Steel and Other Alloys	110108.9	4.5	0.1	48.2	53.0
Blast Furnaces and Steel Mills	39854.4	1.4	0.0	18.0	19.4
Electrometallurgical Products	1171.5	0.0	0.0	0.1	0.1
Steel Wire and Related Products	2133.9	0.3	0.0	0.2	0.5
Cold Finishing of Steel Shape	2931.6	0.0	0.0	0.1	0.1
Steel Pipe and Tubes	2747.9	0.0	0.1	0.0	0.1
Iron and Steel Foundries	12270.6	0.4	0.0	5.0	5.4
Metal Heat Treating	957.1	0.0	0.0	0.5	0.5
Primary Metal Product, NEC	1269.5	2.4	0.0	0.2	2.5
Primary Copper	5548.2	0.1	0.1	0.2	0.3
Primary Lead	1906.1	0.0	0.0	1.0	0.9
Primary Zinc	791.9	-0.2	0.0	0.1	-0.1
Primary Aluminum	7992.0	0.0	0.0	0.8	0.9
Primary Nonferrous Metals, NEC	3351.8	-0.1	0.0	1.5	1.4
Copper Rolling and Drawing	2979.5	0.1	0.0	1.2	7.5
Aluminum Rolling and Drawing	9423.1	0.0	0.0	7.5	2.6
Nonferrous Rolling and Drawing, NEC	2647.9	0.0	0.0	2.6	3.8
Nonferrous Wir Drawing and Insulating	7748.6	0.1	0.0	3.8	3.1
Aluminum Castings	2696.3	0.0	0.0	3.0	0.2
Brass, Bronze, and Copper Castings	559.1	0.1	0.0	0.2	0.3
Nonferrous Castings, NEC	1127.9	0.0	0.0	2.4	2.4

TABLE A-5: TITANIUM DEMAND (Continued)

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Tons)	D_1 Direct to Military Construction (Tons)	D_2 Secondary to Defense (Tons)	D* Total to Defense (Tons)
Paints	6511.8	2.1	0.0	0	2.1
Plastics and Synthetic Products	17549.9	98.2	0.0	553.7	651.9
Fluxes	4633.4	137.5	0.0	39.3	176.8
Paper Products	13063.6	66.1	0.0	904.6	970.7
Rubber Products	50511.2	44.5	0.0	87.0	131.5
Tires and Inner Tubes	12628.3	8.0	0.0	9.9	17.9
Rubber and Plastic Footwear	906.9	0.5	0.0	0.0	0.5
Reclaimed Rubber	44.9	0.0	0.0	0.0	0.0
Fabricated Rubber Product, NEC	4784.1	21.5	0.0	14.6	36.1
Miscellaneous Plastic Product	30514	11.5	0.0	60.6	72.1
Rubber and Plastic Hose and Belting	1633	3.0	0.0	1.9	4.9
Ceramics and Glass	33040.5	52.2	152.3	253.1	457.6
Glass and Glass Products, NEC	5754.4	16.4	4.6	116.2	137.2
Glass Containers	4059	0.0	0	13.7	13.7
Cement, Hydraulic	2606.9	9.3	10.1	6.3	25.7
Brick and Structural Clay Tile	450.2	1.6	3	5.8	10.3
Ceramic Wall and Floor Tile	135	0.0	0	2.3	2.3
Clay Refractories	551.3	0.0	0	0.1	0.1
Structural Clay Products, NEC	113.2	0.0	1.3	0.0	1.3
Vitreous Plumbing Fixtures	303	0.0	0	0.0	0.0
Vitreous China Food Utensils	152.4	0.0	0	0.1	0.1
Fine Earthware Food Utensils	129.9	0.0	0	0.0	0.0
Porcelain Elec Supplies	378	0.0	0	4.7	4.7
Pottery Products, NEC	198.8	0.0	0	2.2	2.2
Concrete Block and Brick	708.1	3.1	4.4	0.0	7.6
Concrete Products, NEC	2409.6	6.3	42.2	0.9	49.3
Ready Mixed Concrete	5616.4	10.8	54.2	0.8	65.8
Lime	514.4	0.0	0	2.1	2.1
Gypsum Products	972.8	0.0	3.2	0.1	3.3
Cut Stone and Stone Products	321.8	0.0	3.2	0.0	3.2
Abrasive Products	1546.5	0.0	0	25.3	25.3
Asbestos Products	40.8	0.0	0	5.2	5.2
Gaskets, Pack and Seal Devices	853.9	0.0	5.6	24.2	29.8
Minerals, Ground or Treated	1235.2	4.7	4.5	3.9	13.1
Mineral Wool	1458.5	0.0	0	18.2	18.2
Nonclay Refractories	1676.7	0.0	16	1.9	17.9
Nonmetal Mineral Product, NEC	853.7	0.0	0	19.0	19.0

TABLE A-6: PLATINUM DEMAND

Economic Sector	Total Domestic Output (Million$)	D_1 Direct to Defense (Lbs)	D_1 Direct to Military Construction (Lbs)	D_2 Secondary to Defense (Lbs)	D* Total to Defense (Lbs)
Automotive	121513.7	184.9	0.0	71.8	256.7
Truck & Bus Bodies	5252.0	0.0	0.0	2.8	2.8
Truck Trailers	3409.0	4.1	0.0	0.0	4.1
Motor Vehicles	74858.0	147.7	0.0	0.0	147.7
Motor Vehicle Parts and Accesories	37994.7	33.1	0.0	69.0	102.1
Chemicals	48369.5	60.4	0.0	2.8	63.2
Industrial Chemls (Inorg & Org)	47943.9	60.4	0.0	1.9	62.3
Gum and Wood Chemicals	425.6	0.0	0.0	0.9	0.9
Petroleum	96251.6	94.9	0.8	51.7	147.4
Ceramics and Glass	5754.4	0.0	0.0	0.0	0.0
Electrical and Electronic	54689.3	1292.9	0.3	1.9	1295.1
Motors and Generators	6044.8	20.2	0.0	0.2	20.4
Industrial Controls	3766.3	7.1	0.0	0.3	7.4
Welding Apparatus	1725.1	1.0	0.0	0.3	1.3
Carbon and Graphite Products	1002.7	0.8	0.0	0.0	0.8
Electrical and Industrial Apparatus, NEC	885.2	0.8	0.0	0.0	0.8
Telephone and Telegraph Apparatus	15081.7	20.3	0.0	0.1	20.4
Radio and TV Communication Equipment	26183.5	1242.8	0.3	0.9	1244.1
Dental & Medical	1090.7	8.0	0.0	0.0	8.0
Jewelry, Precious Metal	1963.4	0.0	0.0	4.8	4.8

APPENDIX B

SUBSTITUTION ANALYSIS

Appendix B provides a proposed framework for the substitution analysis. The overall methodology involves:

- Developing criteria to evaluate direct substitution, process improvements or other conservation techniques - Figure B1;
- Potential issues regarding the form (e.g., process step) of stockpiled strategic/critical materials - Table B1; and
- Methodology for collecting data and classifying technical development affecting strategic/critical material supply and demand at each process stage - Figure B2.

These approaches can be easily supported with previously identified major DOD end-use sectors (e.g., transportation for manganese) and subsectors (e.g., aircraft, aircraft missile engines, etc.) to focus substitution analysis efforts.

FIGURE B-1
IMPACTS OF SUBSTITUTION AND CONSERVATION

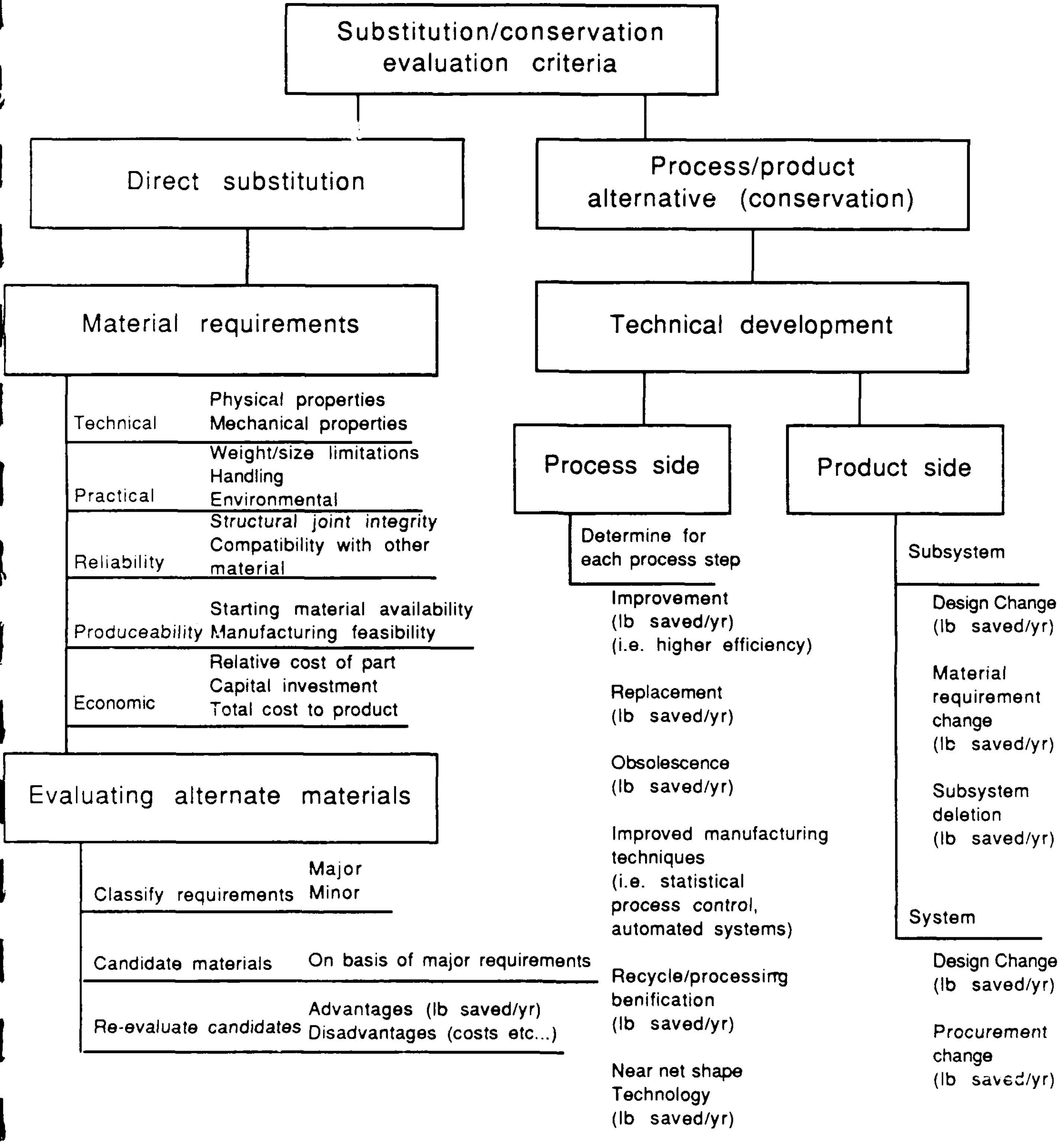
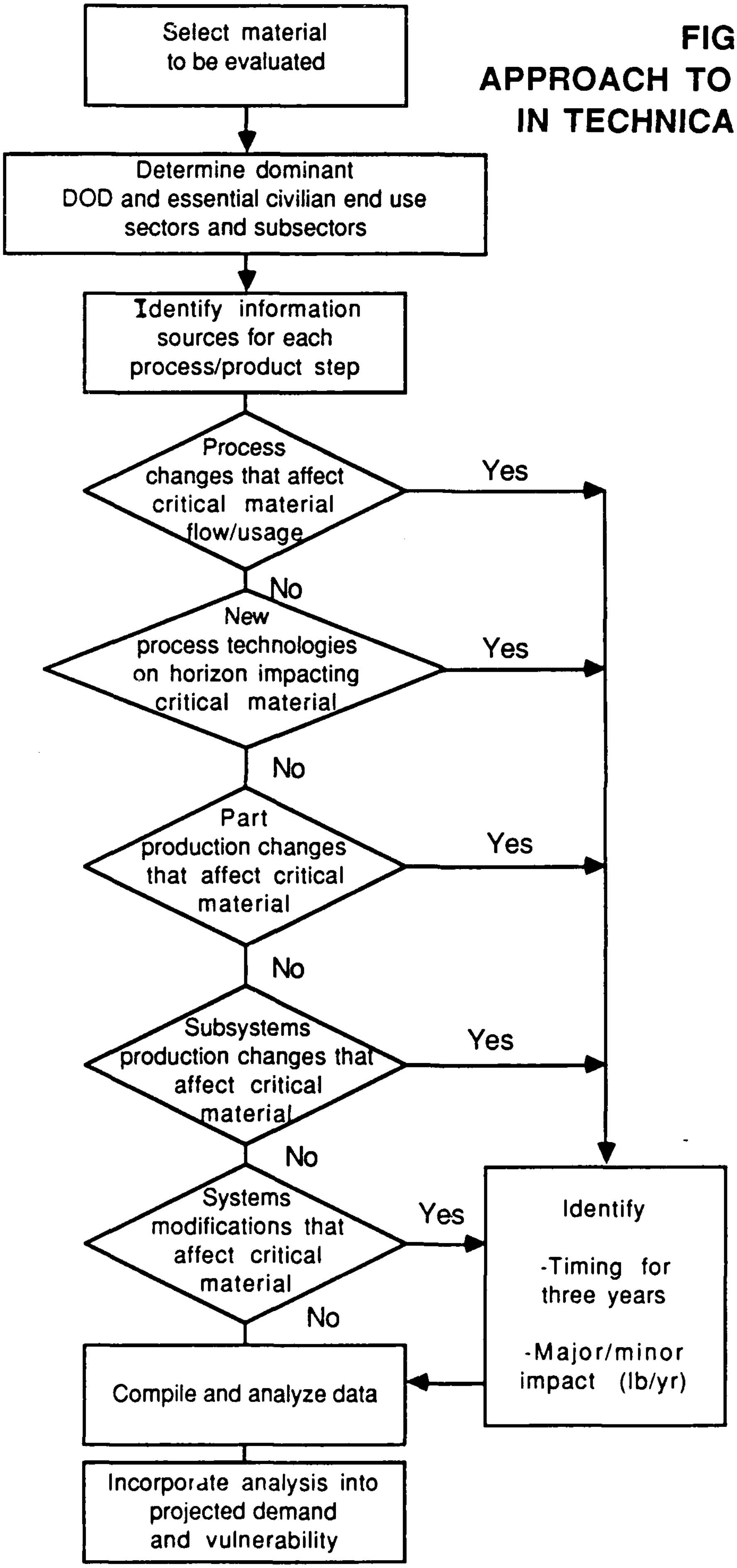


TABLE B-1

STRATEGIC/CRITICAL MATERIAL FORM-RELATED ISSUES

Process Step	Examples of Potential Issues	Information Sources
- Mine (Reserve Base)	• New Reserves Found in U.S. or Canada	• Bureau of Mines • Commodities Specialist
- Mill/Beneficiation	• New Upgrading Techniques for Existing Reserves • Technology Breakthrough for Competitive Concentrate or Alternative Ore Bodies (e.g., Kaolin Clay substitution for bauxite)	• Bureau of Mines • Commodities Specialists
- Smelter/Refinery	• New Smelting Technology with Higher Yields • Industry-wide manufacturing Practices Upgrading (e.g., statistical process controls)	• Bureau of Mines • Commodities Specialists
- Production of Mill Product (e.g., finishing/rolling)	• Increased Process Control Control to Reduce Scrap	• e.g., Fully-integrated Specialty Steel Mills
	• New Alloys Requiring Different Mill Practices and Product Specifications	• e.g., Association of Iron and Steel Engineers (AISE)
- Component Manufacturing	• New Substitute Materials - Ceramics - Plastics - Composites	• e.g., Gas Turbine Engine Manufacturers • e.g., Aircraft Manufacturers
	• Manufacturing Process Changes (e.g., new net shape technology)	• e.g., Society of Manufacturing and Process Engineers (SAMPE Journal)
- Subsystem Fabrication (e.g., jet engine)	• New Substitute Materials	• SAMPE Journal
	• Design Modifications Affecting "Hot Section" Weight Percentage • Revolutionary Design Change for all Composite Engines	• Aircraft Manufacturers
- System (e.g., aircraft, battleship)	• Congressional Support for New System (e.g., SDI) • Appropriated Funding • Composite Intensive Aircraft	• SAMPE Journal • Jane's Defense Weekly

FIGURE B-2
APPROACH TO CLASSIFYING DATA IN TECHNICAL DEVELOPMENTS



APPENDIX C

CAPACITY VULNERABILITY AND DERIVATION OF EQUATIONS

Qualitatively, the framework started with analyzing supply and supply relationships. It was assumed that DOD demands are comparatively inelastic compared to the civilian economy. Two situations representing extremes were considered assuming foreign supplies were curtailed under mobilization conditions:

Case A: **If for a given commodidty DOD demands were relatively small compared to domestic supply capability before mobilization, it appears that there probably would be few "problems" in meeting DOD requirements after mobilization (i.e., there would be sufficient "slack" in the civilian economy to meet all DOD requirements.**

Case B: **If for another commodity DOD demands exceeded domestic supply capability before or after mobilization, it appears there could be major economic dislocation because of the relatively inelastic nature of DOD demands.**

Clearly, this is an oversimplified view of supply and demand, but it led to the thought that a calculated equilibrium price rise for Case A would be less than for Case B for most scenarios. The question was then asked as to whether such a calculated and theoretical price rise could be used as a measure of vulnerability: low calculated price rises means low vulnerability (i.e., Case A above); higher price rises mean high vulnerability (Case B above). It should be noted that this was not thought of as an attempt to predict price rises under mobilization conditions but rather as a potential way to make an initial assessment as to whether one commodity (or form of commodity) was more vulnerable than another.

C.1 Simplified Supply/Demand Functions

Starting from the comparative statics framework discussed in Section 2, the symbols shown in Table C-1 are used in developing the analyses. Note that functional definitions are preceded by "F"; the values of the functions are given by C, D, or S. Coefficients of elasticity are

assumed to be constant throughout this analysis. Throughout, we assume there is a price ("clearing price") under which both DOD and civilian demands are met.

Table C-1. Definitions

FS	=	Domestic supply function (includes secure North American sources)
FS(F)	=	Foreign supply function
FS_T	=	Total supply function: FS + FS(F)
FD_1	=	DOD demand function (primary demand)
FD_2	=	Essential civilian demand function = DOD secondary
FD*	=	$FD_1 + FD_2$
FD_3	=	Non-essential civilian demand function
FD_T	=	Total domestic demand function: $FD_1 + FD_2 + FD_3$
D*	=	Value of $(D_1 + D_2)$ at equilibrium price, P_o, before mobilization
D_3	=	Value of FD_3 at equilibrium price, before mobilization
C	=	U.S. domestic capacity (existing production capacity plus estimated convertible capacity within 12-month period)
V	=	Vulnerability index

We start by defining total demand function, FD_T, given by:

$$FD_T = FD_1 + FD_2 + FD_3 \qquad \text{(eq. C1)}$$

Although FD_2 and FD_3 are primarily civilian demands, we find it more useful to assume here that both primary and secondary DOD demands FD_1 and FD_2 are highly inelastic over the short term of three years or less and combine these terms so that the total demand is given by:

$$FD_T = FD^* + FD_3 \qquad \text{(eq. C2)}$$

The supply side function is simplified by considering only terms representing domestic and foreign sources. By setting supply equal to demand, one obtains:

$$FS + FS(F) = FD_T \qquad \text{(eq. C3)}$$

The supply/demand equilibrium (base case) before mobilization is shown as point P_o Q_o in Figure C-1.

Assume now that mobilization occurs; DOD demands, D*, increases but there is no supply curtailment. After mobilization, the demand curve moves outward to FD_T' as pictorially illustrated in Figure C-1. Under such conditions, the price is expected to rise, and a new equilibrium price satisfying both D* (DOD primary and secondary) and D_3 civilian demands is obtained.

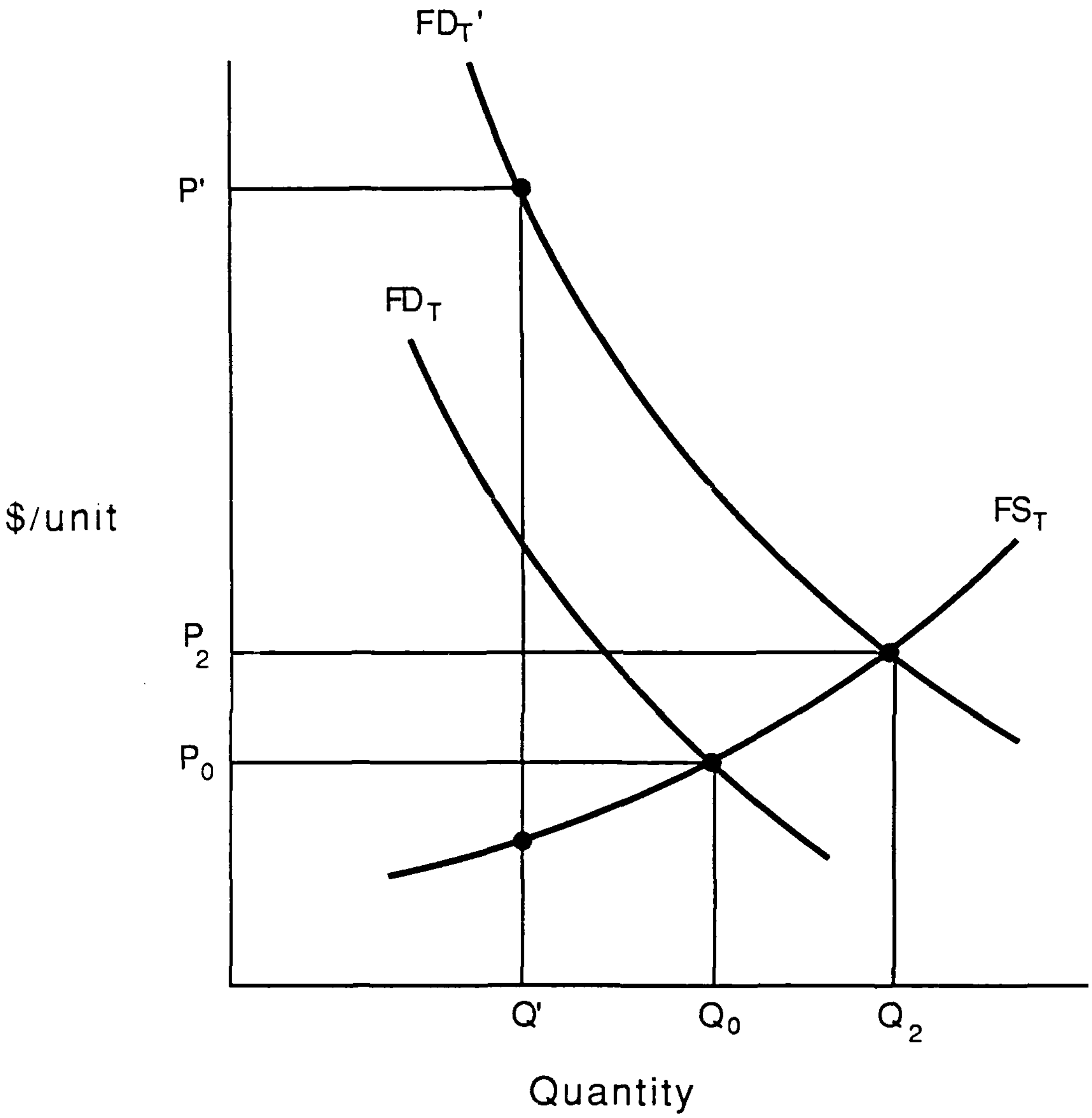
With no supply contraints, a new equilibrium price is established at point P_2 Q_2. We now assume that all foreign supply of ore, matte, refined metal, etc. is totally curtailed under mobilization conditions. In addition, domestic supplies over the short term of three years are usually capacity constrained at some point in the production process (see below). As a result, the supply function in Figure C-1 is limited to domestic sources, and a new equilibrium price is established at point, Q' P'.

C.2 Vulnerability Index

If P' under mobilization is only slightly larger than P_o (before mobilization), there will probably be little dislocations to the economy in allocating the resources under "free market" conditions. However, if P' is much larger than P_o, major dislocations may occur. Some companies will find it hard to pass on price increases; others may be forced to find alternative materials to stay in business; others may be forced out of business. We assume here that the higher the calculated equilibrium price P' for a commodity the greater is the potential dislocation in the domestic economy.

FIGURE C-1

SUPPLY/DEMAND EQUILIBRIUM



P_0Q_0	supply/demand equilibrium (base case)
P_2Q_2	supply/demand equilibrium under mobilization with no capacity constraints
P' Q'	supply/demand equilibrium with capacity constraints, C (i.e., pinchpoints)

The ratio of P' to P_o is called here the vulnerability index, V. We use it as a qualitative and relative measure of estimating whether one commodity or form of commodity is more vulnerable than another (see Section C.5).

C.3 Pinchpoint Concept

In order to relate "capacity" to the supply/demand relationships, it is useful to examine each step (i.e., node) in the production process sequence. As shown in Figure C-2, at each step we look upstream to the raw material suppliers as part of the supply function and downstream to users as part of the demand function.

For example, in Figure C-2 the mill-smelter complex (node 2) looks upstream to domestic mines and imports of ore for supplies while demand is predicated by downstream needs of "customers". In addition, the mill smelter has a nominal or design capacity which under mobilization conditions may be marginally increased by foregoing maintenance or simple debottlenecking. However, for design, construction, and start-up of new capacity requires a timeframe of several years to achieve major increases. For purposes of this study, we assume that the capacity is defined by a nominal or design value, C. At each step in the production process, one has a nominal or design value such as C_1 for a mine in Figure C-2, C_2 for the mill smelter, C_3 for the refinery, etc. Above this design value, incremental capacity (and domestic supply) is assumed to be obtained by a new relationship, $FS = FC'$.

The rest of this section develops the relevant equations to show mathematical relationships between the various factors.

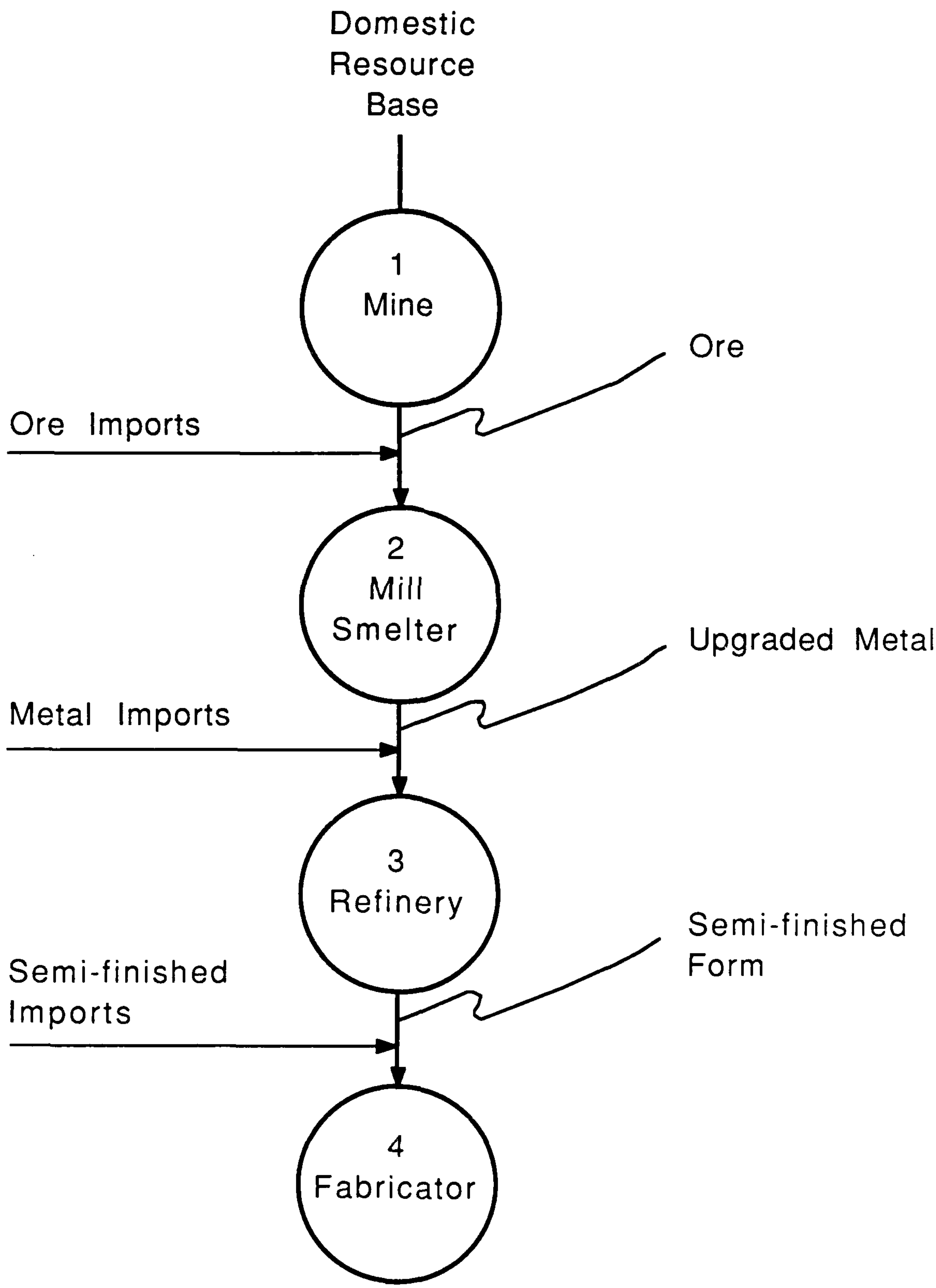
C.4 Mobilization and Import Curtailment

Under mobilization conditions, we now make the following assumption:

- Total demand functions increase from FD_T to FD_T' (Figure C-1) (outward movement of the demand curve as shown in Figure C-1).

FIGURE C-2

NODES IN THE PRODUCTION SEQUENCE ILLUSTRATING "NODE" SUPPLY/DEMAND



- All foreign supply of ore, matte, refined metal, etc. are completely curtailed (i.e., FS(F) = 0).

- Domestic supply increases at each supply node of Figure C-2 up to a node's "capacity" limit, C_i. We assume that once this capacity limit is reached, the domestic supply function is given by FS = FC_i' (see Figure C-3).

The supply/demand equilibrium is given at a new calculated equilibrium price, P', where:

$$S' = D*' + D'_3 \qquad \text{(eq. C-4)}$$

As stated earlier, it is not the objective here to predict the equilibrium price, but rather to use such a calculated value of P' to develop a vulnerability index.

Two cases can now be considered:

- Total domestic demand after mobilization D_T' is less than domestic capacity C or ($D_T'/C < 1$). Since domestic suppliers can supply all needs under mobilization, this case would be considered to be relatively non-vulnerable for the purposes of this study.

- Total domestic demand after mobilization is greater than domestic capacity C. This case is of significant interest to this study. The objective is to try to rank the relative vulnerabilities of different materials and forms of materials. Under such conditions, domestic supply is given by the domestic capacity function node C_i in Figure C-2. Upon setting domestic supply equal to demand:

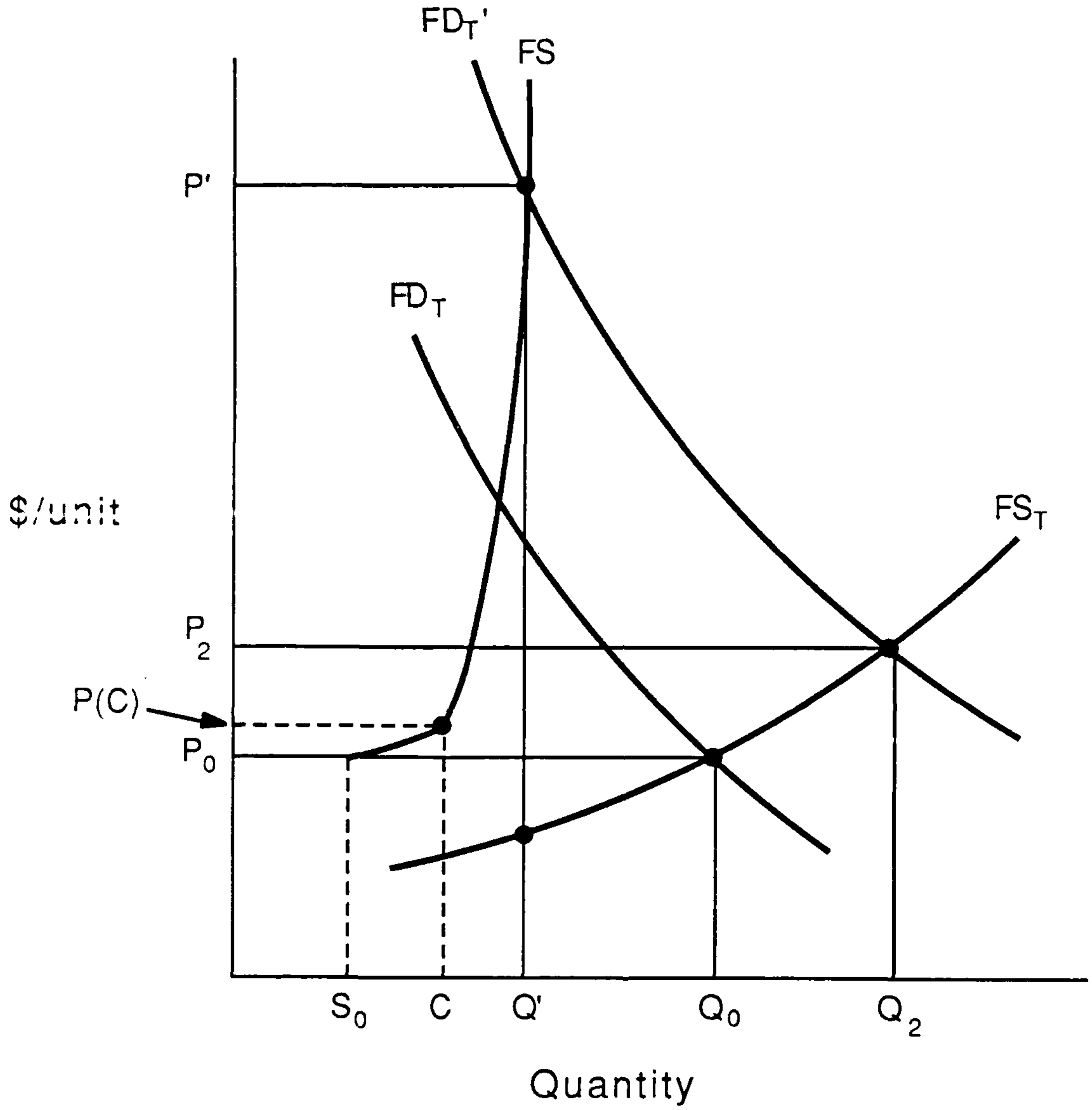
  $$FS = FD*' + FD_3', \text{ or} \qquad \text{(eq. C5)}$$

  at a new equlibrium price, P'

  $$C_i' = D*' + D_3' \qquad \text{(eq. C6)}$$

FIGURE C-3

SUPPLY/DEMAND EQUILIBRIUM WITH DOMESTIC CAPACITY CONSTRAINTS



$P_0 Q_0$	supply/demand equilibrium (base case)
$P_2 Q_2$	supply/demand equilibrium under mobilization with no capacity constraints
$P' Q'$	supply/demand equilibrium with capacity constraints, C (i.e., pinchpoints)

All this equation says is that available supply C_i' is allocated between "downstream" defense ($D^{*\prime}$) and civilian D_3' demands.

Note: If C_i capacity before mobilization is greater than $D^{*\prime} + D_3'$, then one is not capacity constrained, and eq. C6 does not apply. Put another way, if C_i is greater than $D^{*\prime} + D_3'$, this implies domestic capacity can meet all civilian and DOD demands and such a situation indicates the material at this stage of the processing sequence (e.g., an ore, matte, semi-finished form) is not capacity constrained.

By division of eq. C6 by capacity C_i', one has

$$1 = D^{*\prime}/C_i' + D_3'/C_i' \qquad \text{(eq. C7)}$$

Upon:

- Relating demands and capacities after mobilization (primed values) to analagous values before mobilization, and

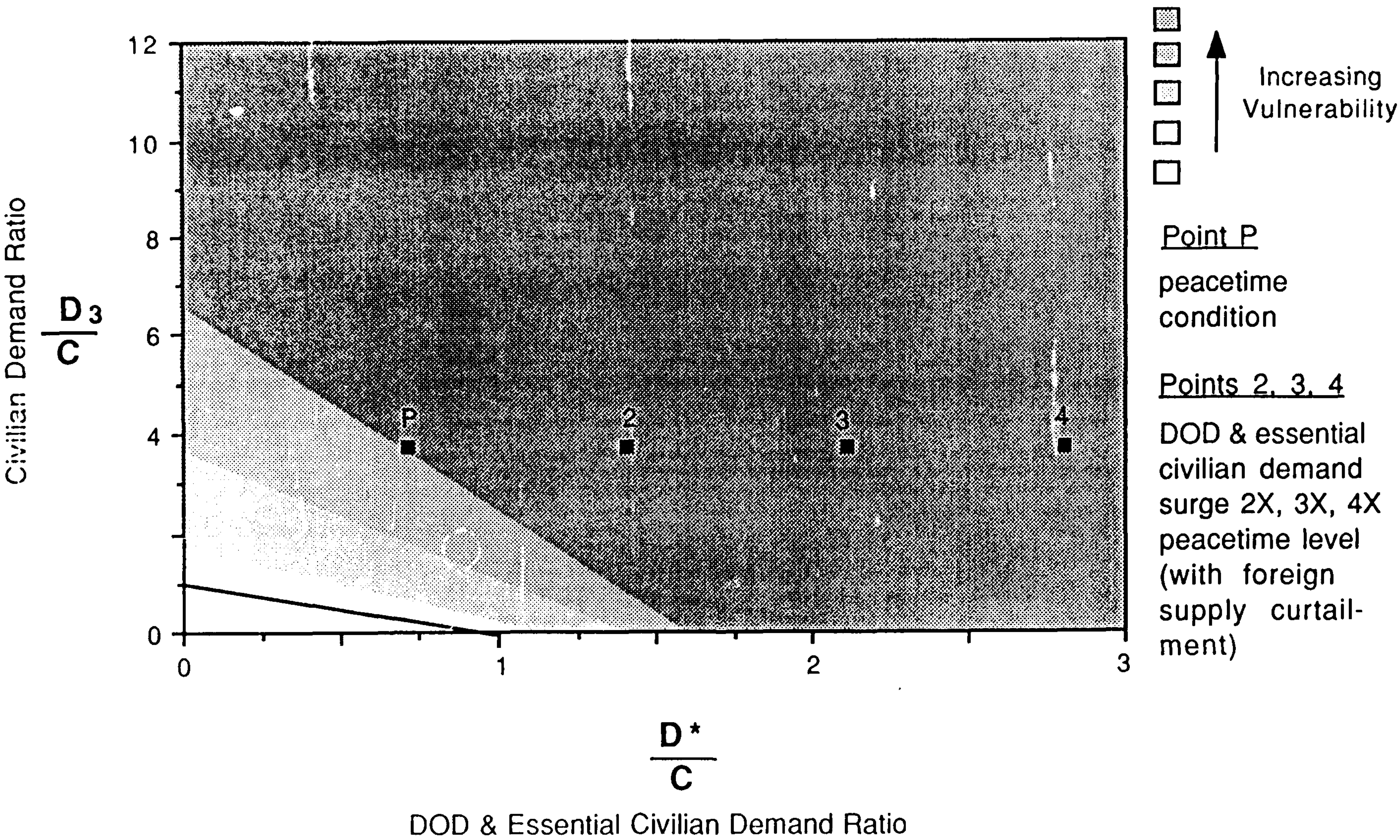
- Defining a vulnerability index (see Section C.5),

a relationship can be developed between D^*/C and D_3/C, as illustrated in Figure C-4. If a point lies in the lower left-hand corner (unshaded area) defined by the line connecting the points $D_3/C = 1$ and $D^*/C = 1$, there is no capacity (or supply) constraint. If the sum of $(D^*/C + D_3/C)$ is greater than 1, then the point represented by D^*/C on the x-axis and D_3/C on the y-axis lies in a shaded part of the diagram. The darker the shaded region, the greater is the vulnerability as discussed below.

C.5 Degree of Vulnerability

In Section C.2, a vulnerability index was defined as the ratio of prices before and after mobilization with import curtailment (P'/P_o in Figure C-1). Within the framework of this analysis, we have made the following assumptions and judgments:

FIGURE C-4
VULNERABILITY ASSESSMENT



- FD* (primary and secondary) DOD demands are highly inelastic. For simplicity, these demands are considered together, and we assume that:

$$FD^* = A^* P^{b^*} \quad \text{(eq. C8)}$$

where

b* is the coefficient of demand elasticity for DOD demand
P is price, and
A* for the purposes of this analysis over a short-term timeframe is a constant; it includes all non-price related factors (e.g., population, GNP, etc.)

- Similarly, the civilian demand is given by:

$$FD_3 = A_3 P^{b_3} \quad \text{(eq. C9)}$$

Supply and demand ratios before and after mobilization are now examined and related to prices:

- Under mobilization conditions and no curtailment of foreign supplies, we assume the DOD demand (primary and secondary) moves outward (horizontally) by a factor "n" as defined below:

  - The new DOD demand curve is given by primed quantities

$$FD^{*\prime} = A^{*\prime} P^{b^{*\prime}} \quad \text{(eq. C10)}$$

  - At the equilibrium price before mobilization (P_o), n is defined as the demand ratio of D*' to D*

$$D^{*\prime}/D^* = n$$
$$= A^{*\prime} (P_o^{b^{*\prime}})/A^* P_o^{b^*} \quad \text{(eq. C11)}$$

- Solving for $A^{*\prime}$ in eq. C11

$$A^{*\prime} = n\, A^{*}(P_{\circ}^{\,b^{*}})/P_{\circ}^{\,b^{*\prime}} \qquad \text{(eq. C12)}$$

- substituting the value of $FD^{*} = A^{*}P_{\circ}^{\,b^{*}} = D^{*}$ (see eq. C8) into eq. C12 and then substitution of $A^{*\prime}$ into eq. C10 yields:

$$FD^{*\prime} = D^{*}\, n\, (P'/P_{\circ})^{b^{*\prime}} \qquad \text{(eq. C13)}$$

where P' represents the new price after mobilization

- From eq. C9, the civilian demand ratio reflecting conditions after mobilization to before mobilization is given by:

$$D_3'/D_3 = (P'/P_{\circ})^{b_3}$$

where $P_{\circ}$ is the equilibrium price before mobilization

or the function FD_3' is given by

$$FD_3' = D_3\, (P'/P_{\circ})^{b_3} \qquad \text{(eq. C14)}$$

These equations assume that the civilian sector demand relationship (eq. C9) does not shift as a result of mobilization.

Assume for the moment that capacity is constrained to premobilization conditions, namely, C and that domestic industry before mobilization is operating at design capacity, C. Upon substituting eq. C13 and C14 into eq. C7, one obtains:

$$1 = n\, D^{*}\, (P'/P_{\circ})^{(b^{*\prime})}/C + D_3\, (P'/P_{\circ})^{(b_3)}/C \qquad \text{(eq. C15)}$$

(In the next section, the constraint of constant C is relaxed.)

After mobilization, a new calculated price P' is established for the commodity of interest. The higher the new short-term equilibrium price,

the greater will be the dislocations in the economic sector (i.e., a 20% increase in price will have only a modest effect while a 500% increase will probably have major impacts). Thus, the magnitude of the price rise is an important measure of vulnerability. If there are innumerable civilian substitutes available to meet DOD demand, then the price rise after mobilization will be small and the vulnerability modest. By letting the vulnerability index $V = P'/P_o$, eq. C15 becomes:

$$1 = n\, V^{(b^{*\prime})}\, D^*/C + V^{(b_3)} D_3/C \qquad \text{(eq. C16)}$$

With the relative magnitude of demand elasticities, $b^{*\prime}$ and b_3, estimated, V can be calculated since D^*/C and D_3/C are known (i.e., demand to capacity ratios before mobilization for the DOD and civilian sectors). Alternatively, for a given value of V, a relationship can be developed between D^*/C and D_3/C (see Section C.7). This is illustrated in Figure C-4.

- Movement away from the lower left-hand corner (unshaded area) to the upper right-hand corner (increasingly darker shaded areas) indicates higher or increased vulnerability (i.e., greater potential for economic dislocations).

- The vulnerability increases more rapidly on a linear basis with movement along the DOD axis (x-axis) as compared to movement along the civilian demand axis (y-axis), i.e., a 50% increase in DOD demand has more vulnerability ("price") impact than a 50% increase in the civilian demand. This is a logical consequence of assuming that DOD demand, D*, is much more inelastic than civilian demand.

In Section C.5, we assumed that:

- Demand is greater than capacity, and

- Domestic industry was operating at its design capacity, C, before mobilization (S = C).

We now pose the question: What is the implication of industry operating below design capacity before mobilization (i.e., idle capacity or shut-down capacity before mobilization conditions)? This situation is pictorially represented in Figure C-3. Before mobilization, P_o is the equilibrium price for the commodity while domestic industry supplies a quantity S_o to the domestic economy assuming no exports. (For most critical materials of interest, the U.S. is import-dependent so that net exports are negligible (net exports = exports - imports). After mobilization, we assume demand exceeds domestic capacity, C. In Figure C-3, this is considered in two steps:

- Domestic capacity is shown to supply up to a quantity C (design capacity) corresponding to a price P (C).

- Above plant design limits, C, capacity increases come at increasingly higher costs especially over the shorter term (three years or less). Capacity increases can be accomplished, for example, by debottlenecking, foregoing long-term maintenance, and so on. A new equilibrium price (P') is established at a capacity C' (=Q') as illustrated in Figure D-3.

Mathematically, the above thoughts can be represented by:

$$S = S_o \, (P/P_o)^e \text{ for } S < C \qquad \text{(eq. C17)}$$

$$S = C \, [P/P(C)]^{e'} \text{ for } S > C \qquad \text{(eq. C18)}$$

where:

e = coefficient of supply elasticity over the short term up to the design capacity limits.

e'= coefficient of supply elasticity over the short term over the design capacity limits.

As illustrated pictorially in Figure C-3, if capacity is merely idled, it is expected to be reactivated with only modest price increases. For example, engineering judgment suggests that idled ferroalloy capacity could be reactivated and made economically viable with only modest price increases on the order of 10-20%. Such judgment is indirectly supported by a prior study for FEMA in the steel industry (U.S. Steel Industry Minimum Economic Industrial Base, September, 1985). This showed that for six product lines in steel (hot rolled strip, cold rolled strip, pipe, plate, etc.) an increase of 20% in list prices would have made 75% to 90% or more of idled capacity economic to operate. Thus, this suggests that the elasticity coefficient for idled capacity is relatively high; the observation is further supported by recent price rises in the steel industry and higher capacity utilization.

However, like an automobile operating at its highest speed ("accelerator on the floor"), increases in capacity beyond the design capacity C can be only obtained over the short term with significantly higher costs. (In these mature industries being considered for this analysis, profit margins are typically less than 10% of sales and prices are closely related to costs: $\pm$10%.) Thus, we assume higher costs correlate with higher prices.

To put these thoughts in perspective, a two to ten fold price rise may increase production by only 10-20% above the plants' design limits over the short term. There are few historical examples to cite to verify such an assumption, but from an engineering point of view, plants are often designed with excess production capacity of 10-20% designed in key process units of the plant. The Engineering Sciences have advanced to the point where most plants in the mature industries being considered can be "sized" within an accuracy of 10-20% in the design process. Quite often the tolerances are even tighter in these competitive industries. Few, if any, plants can be considered to be designed with excess capacities of 50% or more.

As a result of such considerations, it is believed reasonable to assume that:

- It would take substantial price rises to bring on additional capacity in the short term above design capacity limits. For purposes of this analysis, we assume an elasticity coefficient for supply under such conditions in the order of 0-0.3.

- Idled capacity can be brought on line with only modest price increases, i.e., the supply function is very elastic up to the design capacity limit C (that is, a 10-30% price increase would probably reactivate all idled capacity). Since domestic plant production levels may be typically 50-90% of domestic capacity, this would generally imply an "elasticity" in the capacity function e of greater than 1:

$$e = (\log S'/S_o)/\log (P'/P_o) \qquad \text{(eq. C19)}$$

Examples in steelmaking can be found in the aforementioned steel study for FEMA. As a result of such considerations, it is believed reasonable to assume that modest price rises of 10-20% will reactivate the majority of idled or excess capacity, and the coefficient of supply elasticity is assumed to be greater than units. For purposes of this analysis where attempts are being made to identify potential causes of significant price rises, we assume that the price to justify economically operating at capacity limits is roughly equal to current market prices ($\pm$10 to 20%). In other words, price increases of 10-20% can be considered to be insignificant from the viewpoint of determining vulnerability V where one is trying to identify theoretical price rises of 100% or more. Thus, from the viewpoint of this analysis we assume:

$$P(C) = P_o \text{ and}$$
$$S = C = C\,(P'/P_o)^{e'} \text{ for } S > C \qquad \text{(eq. C20)}$$

or

$$C' = C\,(V)^{e'} \qquad \text{(eq. C21)}$$

Substitution of the above value of C' into eq. C16 yields:

$$1 = n\ V^{(b^{*\prime})}\ D^*/(C\ V^{e'}) + V^{(b_e)}\ D_3/(C\ V^{e'}) \qquad \text{(eq. C22)}$$

C.7 Numerical Example

An example to illustrate how one can develop a vulnerability "map" is discussed below:

- assume demand elasticities:

  $b_3 = -0.7$, where b_3 represents the demand coefficient for the relatively elastic civilian economy

  $b^* = -0.1$, where b^* represents the demand coefficient of the relatively inelastic DOD (primary and secondary) demands

  $e = 0.1$, where e is the domestic supply elasticity when demand ("supply required") is above the nominal or design capacity C

- substitution of these values in eq. C16 yields

$$1 = n\ V^{-0.1}\ D^*/(C\ V^{0.1}) + V^{-0.7}\ D_3/(C\ V^{0.1}) \qquad \text{(eq. C23)}$$

Note that values of D^* and D_3 are those existing before mobilization.

By now assuming values of V = 1, 2, 5, and 10, one can plot D^*/C versus D_3/C. Results are shown in Figure C-4 where the boundaries from one shaded area to another represent the vulnerability values chosen (1, 2, 5, and 10). For example, if V = 10 and setting $D_3/C = 0$ and $n = 1$ (representing import curtailment but no increase in DOD mobilization demands):

$$1 = 10^{-0.8}\ D^*/C, \text{ or}$$

$$D^*/C = 6.3$$

This is represented at the y intercept (i.e., $D^*/C = 0$) in Figure C-4 showing the transition from one shaded area to another. Obviously, other values of b^*, b_3, e and V can be chosen. For example, Table C-2 provides a sensitivity analysis for $V = 10$ (and $n = 1$) in terms of how changes in the assumed values of b_3, b^* and e affect the x and y intercepts of the interface in the shaded area. It is seen, however, that with such new values, the general character of the vulnerability map, Figure C-4, remains the same provided that the DOD demands remain relatively inelastic and civilian demands are relatively elastic.

With such assumptions, one can develop a series of maps each showing areas ranging from the unshaded (non-vulnerable area) in the lower left-hand corner to progressively higher shadings (and vulnerability) to the upper right-hand corner. However, no great credence should be given to the absolute values of the coefficients of elasticity and vulnerabilities V. The map is useful largely for identifying the potential relative vulnerability of different commodities or forms of commodities under mobilization conditions. We have used the vulnerability map shown in Figure C-4 throughout this document (elasticity coefficients and values of V have not been changed from figure to figure and thus the relative shading remains the same).

Table C-2. Sensitivity Analysis
Basis: $V = 10$

	Base Case(a)	A	B	C	D	E	F
		Alternative Case					
n	1	1	1	1	1	1	1
V	10	10	10	10	10	10	10
b_3	-0.7	-0.8	-0.6	-0.7	-0.7	-0.7	-0.7
b^*	-0.1	-0.1	-0.1	-0.2	-0.0	-0.1	-0.1
e	+0.1	+0.1	+0.1	+0.1	+0.1	0.2	0
"y" intercept[(b)] D_3/C	6.3	7.94	3.98	6.3	6.3	7.94	5.0
"x" intercept[(c)] D^*/C	1.58	1.58	1.58	2.0	1.25	2.0	1.26

(a) see Figure C-4

(b) intercept of line representing $V = 10$ with y ($=D_3/C$) axis

(c) intercept of line representing $V = 10$ with x ($=D^*/C$) axis

APPENDIX D

MANGANESE INDUSTRY STRUCTURE

Overview

Manganese is one of the vital elements of an industrial society; virtually all steels must contain some manganese. There exist no known substitutes for manganese in steel production. Over 90% of all manganese produced is used in the ferrous and nonferrous metallurgical industry for improving strength and workability properties. The remaining amount is consumed generally as manganese dioxide in the battery industry or in other chemical forms in chemical industries.

The United States is highly dependent on imports for its supply of manganese regardless of form. Over the past few years, no manganese ore containing 35% or more manganese was domestically produced. In 1985, the United States imported manganese in ores, concentrates, metals, and ferroalloys (ferromanganese and silicomanganese) for total U.S. apparent consumption of 698,000 tons of contained manganese [1].

In this appendix, an analysis of U.S. domestic capacity for the production of manganese product forms consumed will be compared against segmented U.S. demand to evaluate capacity vulnerability.

Geographic Distribution

Manganese is the 12th most abundant element in the earth's crust and is relatively widespread. It is a low-value abundant commodity relative to other ferroalloy materials such as chromites.

Manganese is found in the form of numerous mineral assemblages. The most important of these minerals include bixbyite, braunite, cryptomelane, hausmannite, jacobsite, pyrolusite, rhodochrosite, romanechite (psilomelane), and wad. All of these minerals are oxides, mixed oxides or silicates with the exception of rhodochrosite which is a carbonate.

Australia, Brazil, Gabon, Ghana, the Republic of South Africa, and the U.S.S.R. all produce some form of high-grade product for metallurgical purposes. The Chiatura Basin is the principal source of U.S.S.R. material. The Republic of South Africa has at least 10% of its production in ores containing greater than 48% manganese content. Morocco, Australia, Brazil, and India are other principal sources of ore for chemical purposes. Battery grade ore is provided mainly by Gabon, Mexico, Ghana, and Greece [1,2].

Manganese ore is smelted into ferromanganese and silicomanganese in many countries. Ferroalloy plants used to be located primarily in consuming and steel-producing countries but increasingly are located in ore-exporting countries. The leading producers are believed to be U.S.S.R., China, Japan, the Republic of South Africa, and France producing greater than 60% of the total [1].

The only existing manganese ferroalloy production facility in the United States in 1987 is Elkem Metals of Marietta, Ohio. About one-quarter of

Manganese metal is produced in the United States by the previously mentioned Elkem facility and Kerr-McGee Chemical Corporation in Hamilton, Missouri, by an electrolytic process.

World production capacity for synthetic manganese dioxide (excluding centrally planned economy countries) was 180,000 tons per year in 1983 of which 80% was electrolytic manganese dioxide. Leading producers are located in Japan, Greece, Ireland, United States, Belgium, Brazil, and India [1].

Grades and Specifications

Manganese content of commonly traded ores, concentrates, nodules, and sinter for metallurgical applications generally range from 38% to 55% with 48% used as a standard for pricing. In addition to manganese content, quality is determined by level of impurities such as iron, alumina, silica, lime, and phosphorus (not to exceed 0.2%) [1].

The composition of ores used for battery applications or chemical purposes are approximately the same as metallurgical grade ores. For battery grade ores, the manganese content is expressed in terms of manganese dioxide (MnO_2), which contains 63% manganese. Manganese dioxide ores typically contain from 70% to 85% MnO_2 [1].

The principal manganese ferroalloys are ferromanganese which is subdivided into standard high-carbon, medium-carbon, and low-carbon grades; silicomanganese; and ferromanganese-silicon (essentially a low-carbon silicomanganese). Maximum carbon content for ferromanganese grades are 0.75%, 1.5%, and 7.5% for the low-, medium-, and high-carbon grades, respectively. Maximum carbon content for silicomanganese grades are 3.0% and 0.08% for high-carbon silicomanganese and ferromanganese-silicon, respectively. Specifications are set forth for manganese ferroalloys by The American Society of Testing and Materials (ASTM). ASTM specifications for most grades of manganese metal call for a total manganese content of at least 99.5%. Nitrogen-bearing grades specify 4.0% to 6.5% nitrogen displacing manganese content with higher permissible carbon levels.

MANGANESE INDUSTRIAL APPLICATIONS

The importance of manganese is linked to the functions it performs as a desulfurizing agent, deoxidizing agent, alloying element, and from its chemical properties. There are no alloy systems with manganese as the base metal.

Manganese is a critical element in the production of steels and cast iron. Manganese is used to control oxygen and sulfur impurities in steel to assure workability. Manganese also increases strength, toughness, hardness, hardenability of steel, and inhibits the formation of carbides that embrittle grain boundaries. Manganese content of steel, averaged over all grades, is about 0.7%.

Manganese is an important constituent of several nonferrous alloy systems, in particular, aluminum alloys. Manganese in aluminum generally improves corrosion resistance [4]. Aluminum beverage cans and food handling

equipment contain 1% or more manganese. Copper-based manganese bronzes are used for marine propellers and fittings, gears, and bearings [3,4,5].

Other minor uses of manganese include manganese dioxides in the form of natural ores, a synthetic dioxide produced electrolytically or by chemical process, or a blend of natural and synthetic material for battery dry cells.

Manganese ore is used as an oxidant in hydroquinone production with a manganese sulfate by-product. Potassium permanganate is a powerful oxidant used in water purification and treatment. Manganese sulfate and manganous oxide are used as soil conditioners. Several forms of manganese are used in the manufacture of welding rods [6].

MANGANESE SUPPLY/DEMAND RELATIONSHIPS

Breakdown of U.S. Manganese Consumption by Product Form

U.S. manganese consumption is segmented into manganese product forms in Figure D-1. With the primary usage of manganese relating to steel production, 630,000 tons of manganese (90.2% of total consumption) was consumed as a manganese ferroalloy in 1985. The next largest usage is battery grade MnO_2 with only 39,000 tons or 5.6% of total manganese demand. Manganese metal and miscellaneous chemical applications combined total much less than 1% of total manganese demand.

Manganese: Supply/Demand Relationship-1985

A world supply/U.S. domestic demand relationship for manganese is shown in Figure D-2. As indicated, of the estimated 9.7 million tons of manganese mined globally in 1985, only 2,000 tons were produced in the United States. Imported metallurgical ore, ferroalloys, and manganese metal total 583,000 tons in 1985 primarily directed at iron and steel industry applications. Comparing values in Figure D-1 and Figure D-2 indicates that approximately 92% of consumed manganese ferroalloys and metal were supplied by either imported metallurgical ore converted to ferroalloys or imports as ferroalloys and manganese metal. Similarly, Arthur D. Little estimates that 66% of U.S. domestically consumed manganese dioxide is imported. Of the total U.S. manganese demand (698,000 tons) in 1985, 76% is consumed in four economic subsectors--construction, transportation, machinery, and other.

Manganese Ferroalloy Domestic Supply/Demand Relationship: 1975-1985

A historical perspective of the United States dependence on foreign capacity to supply domestic demand is shown in Figure D-3. The closest U.S. domestic production of ferroalloys came to meeting U.S. domestic demand was in 1975 when 64% of ferroalloy demand was domestically produced. In 1985, less than 25% of domestic ferroalloy demand was produced in the United States. This percentage has decreased since 1985.

FIGURE D-1

Total U. S. Manganese Consumption 1985

(Thousand Short Tons)

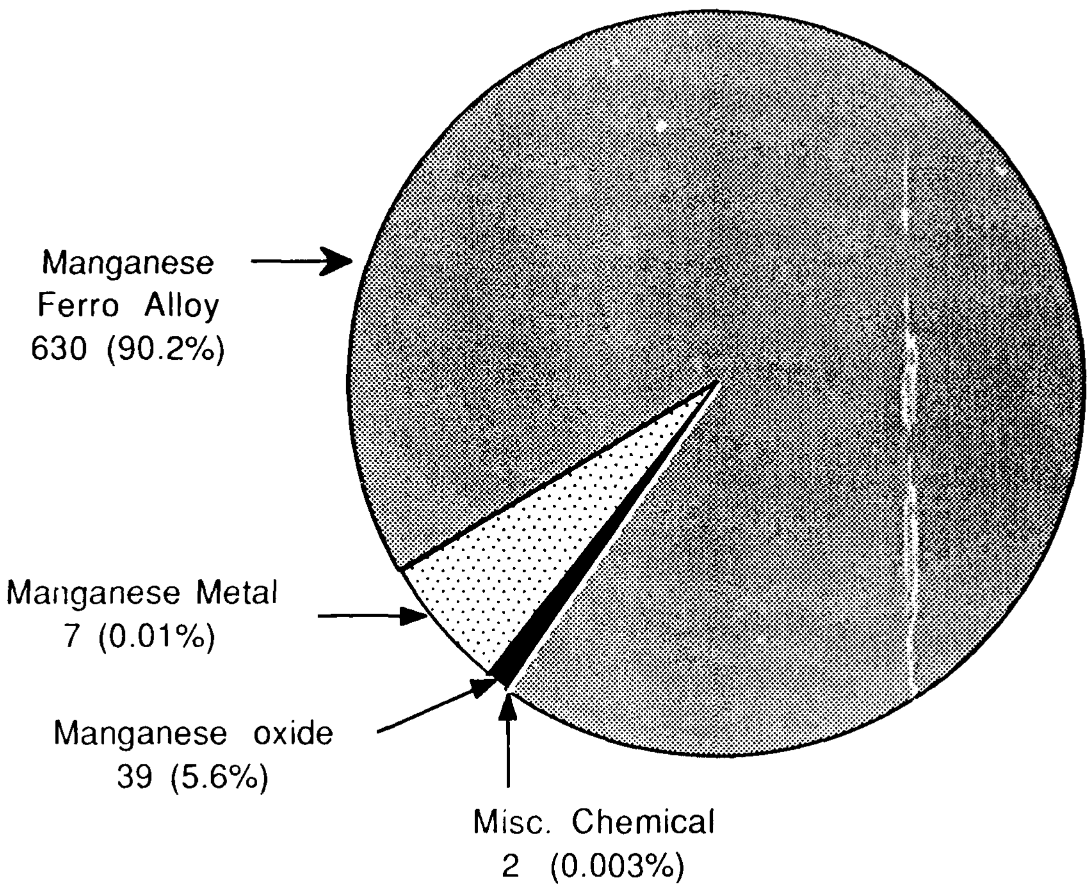
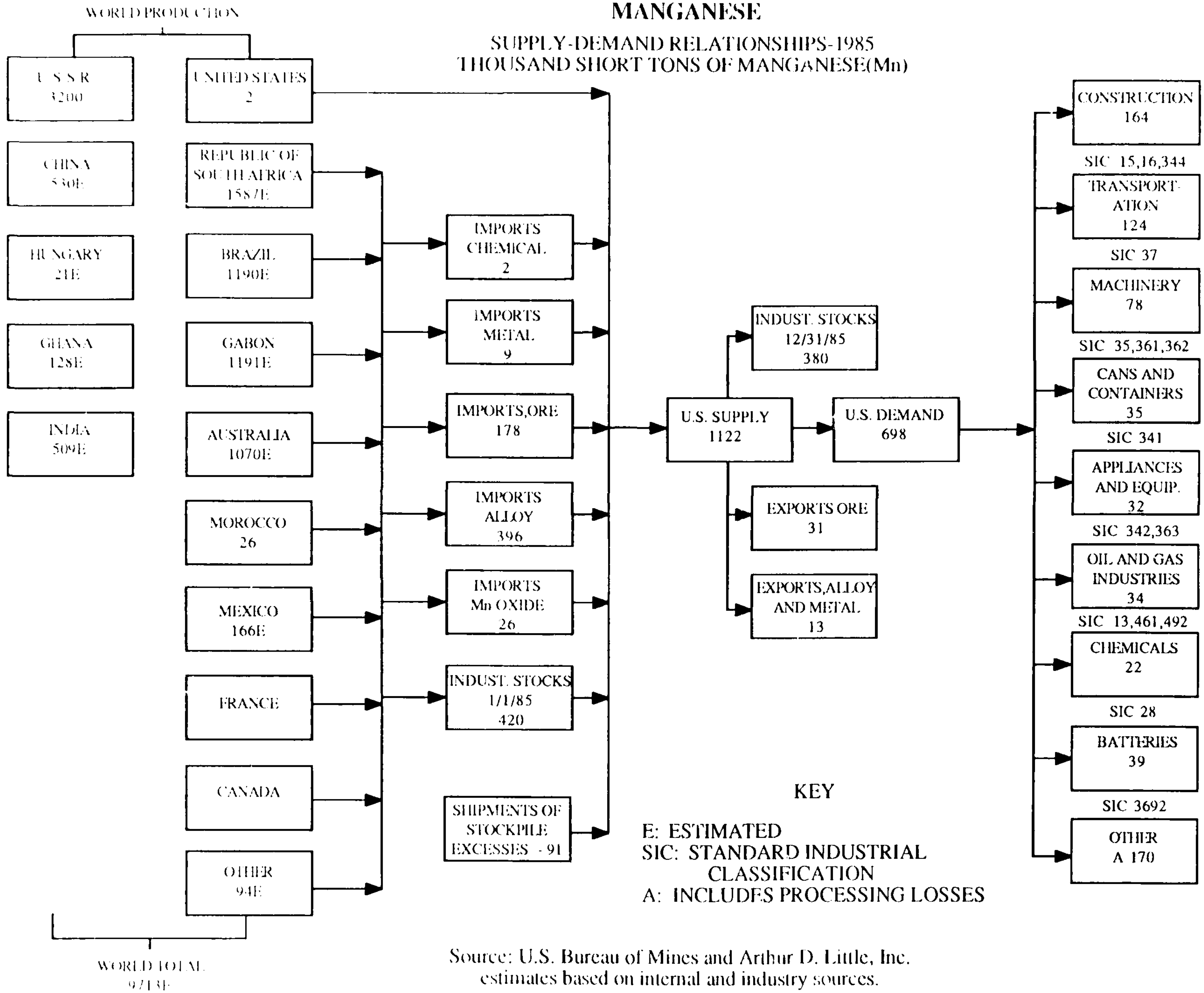


Figure D-2
MANGANESE

SUPPLY-DEMAND RELATIONSHIPS-1985
THOUSAND SHORT TONS OF MANGANESE(Mn)

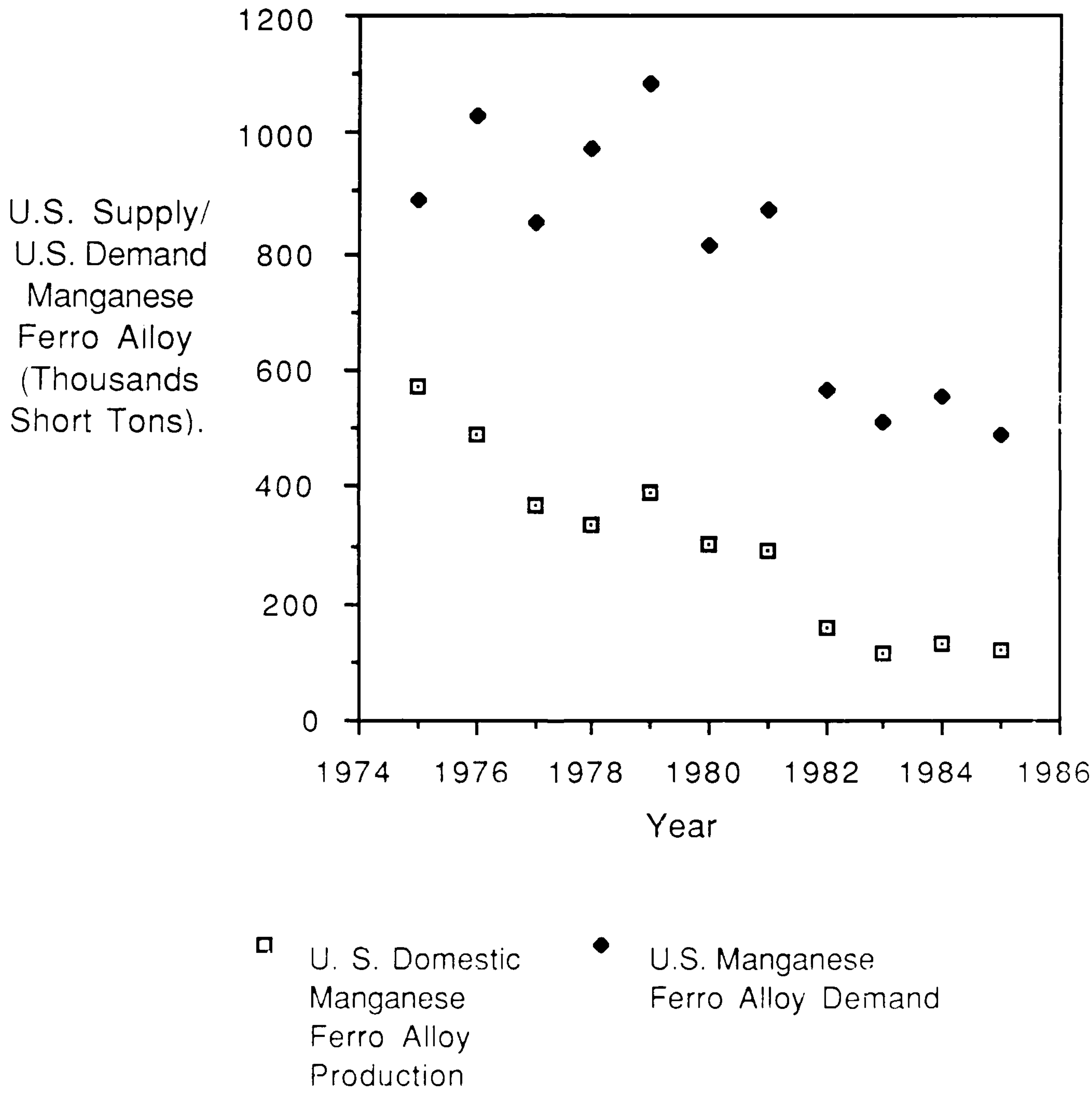


KEY

E: ESTIMATED
SIC: STANDARD INDUSTRIAL CLASSIFICATION
A: INCLUDES PROCESSING LOSSES

Source: U.S. Bureau of Mines and Arthur D. Little, Inc. estimates based on internal and industry sources.

Figure D - 3
Manganese Ferro Alloy Domestic Supply - Demand Relationship, 1975-1985



Source: U.S. Bureau of Mines

Domestic Producers of Manganese Products-1986

U.S. producers of ferromanganese, silicomanganese, manganese metal, and manganese dioxide are listed in Table D-1. Elkem Metals Co. is the only existing domestic ferromanganese producer with an estimated annual capacity of 200,000 tons per year. Silicomanganese alloys are produced both at Elkem in Marietta, Ohio, and SKW Alloys Inc. in Calvert City, Kentucky.

Primary and Secondary Defense Demand

Critical to this analysis of capacity/demand balance is the segmentation of total U.S. domestic demand (D_T) into its three components--non-essential civilian demand (D_3), primary DOD demand (D_1), and secondary DOD demand or "essential civilian demand" (D_2). Previous analysis by Arthur D. Little, Inc., for FEMA using the Inforum Database converted domestic manganese demand in U.S. dollars to tons manganese for primary and secondary DOD end-use. This analysis in Appendix A further segmented domestic manganese demand into end-use economic sectors--construction, transportation, machinery, cans and containers, appliances and equipment, oil and gas industry, chemicals, batteries, and other.

Manganese Form Consumed for Each Economic Sector

In order to analyze the capacity/demand balance for a particular material process/product form, the percentage of the various product forms being supplied to particular end-use economic sectors must be estimated. In the case of manganese, this was relatively simple with only five process/product forms:

- Mining/ore
- Smelting/ferroalloys
- Arc furnace or electrolytic/manganese metal
- Electrolytic or chemical/MnO_2
- Chemical/chemical

Segmentation of total domestic demand in 1985 for each economic sector by manganese product form is shown in Figure D-4. In addition, the segmentation of total domestic demand into estimated and essental civilian DOD demand (D*) and civilian demand (D_3) allows the computation of manganese domestic demand on a process/product form basis also shown in Figure D-4.

MANGANESE CAPACITY ANALYSIS

Manganese Vulnerability Analysis Data

Segmentation of total U.S. domestic manganese demand into estimated DOD and essential civilian categories in Appendix A, breakdown of U.S. manganese demand by process/product form in Figure D-4 along with supply and capacity estimates are compiled and consolidated in Table D-[illegible]

- [illegible] and essential civilian demand amounting to an estimated total [illegible] thousand short tons [illegible] calculated from Figure D-4 [illegible]

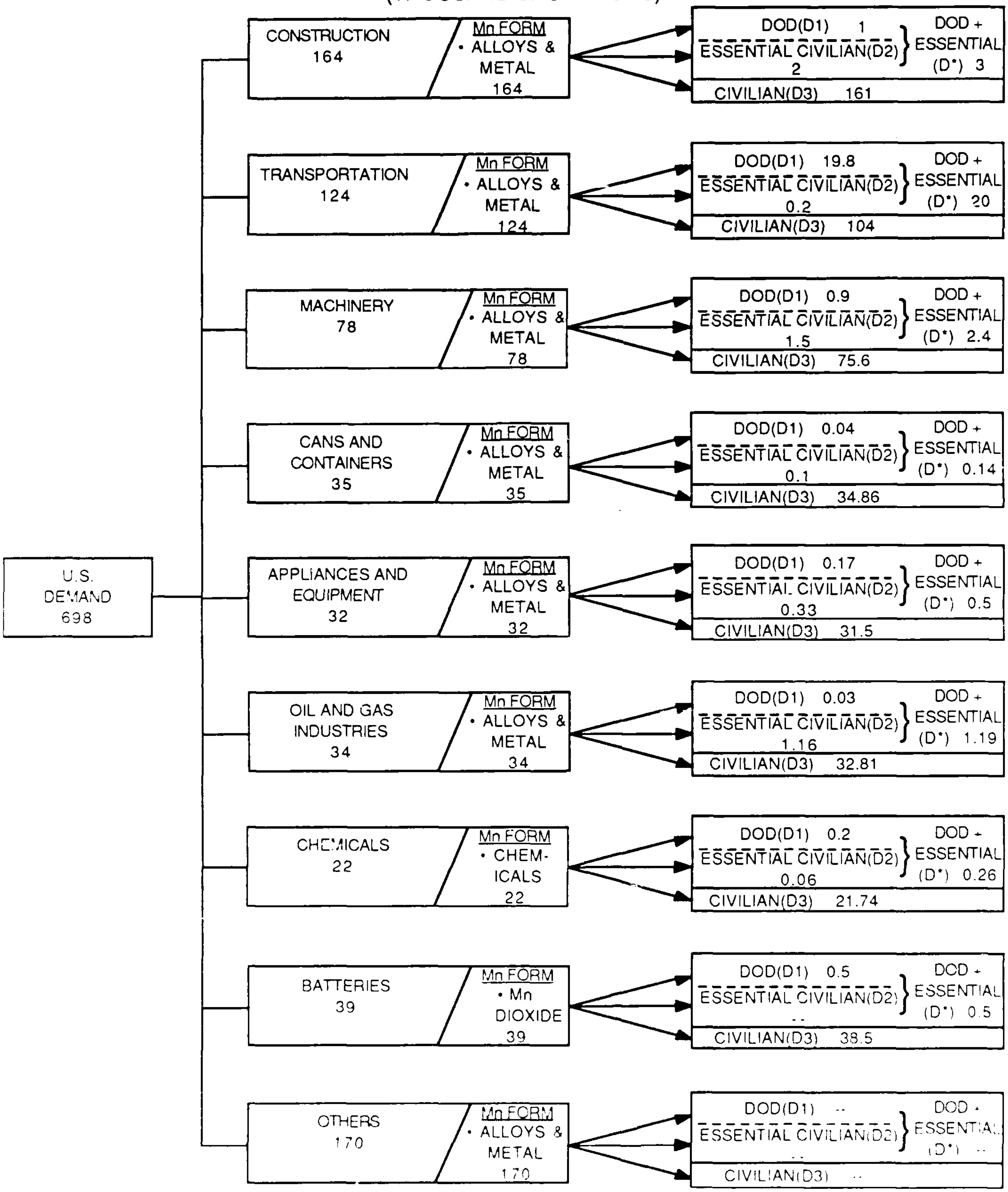
TABLE D - 1

DOMESTIC PRODUCERS OF MANGANESE PRODUCTS IN 1986

Company	Plant Location	Products[1]				Type of Process
		FeMn	SiMn	Mn	MnO_2	
Chemetals Inc.--------	Baltimore, MD----	--	--	--	X	Chemical.
Elkem Metals Co.------	Marietta, OH.-----	X	X	X	--	Electric furnace and electrolytic.
Kerr-McGee Chemical Corp	Hamilton, MS-----	--	--	X	--	Electrolytic.
	Henderson, NV----	--	--	--	X	Electrolytic.
Ralston Purina Co. Eveready Battery Co.	Marietta, OH.-----	--	--	--	X	Electrolytic.
RAYOVAC Corp.: ESB Materials Co.	Covington, TN----	--	--	--	X	Electrolytic.
SKW Alloys Inc.--------	Calvert City, KY--	--	X	--	--	Electric furnace.

[1] FeMn, ferromanganese; SiMn, silicomanganese; Mn, electrolytic manganese metal; MnO ,2 synthetic manganese dioxide.
Source: U.S. Bureau of Mines.

FIGURE D-4
U.S. MANGANESE DEMAND BREAKDOWN
(THOUSAND SHORT TONS)



Source: U.S. Bureau of Mines and Arthur D. Little, Inc.
Estimates based on Inforum Data

TABLE D-2

MANGANESE VULNERABILITY INDEX DATA

Data in 1000 tons per year[1]
Contained Manganese

MANGANESE		TOTAL Mn DEMAND (D_T)	DOD & ESSENTIAL CIVILIAN DEMAND (D^*)	EXISTING & CONVERTIBLE DOMESTIC CAPACITY (C)	DOMESTIC SUPPLY (S)	NON-DOMESTIC SUPPLY	CIVILIAN DEMAND (D_3)
PRODUCT FORM	PROCESS STAGE						
ORE	MINING	178	Use Total Below	40[1]	2	9,711	150
FERRO ALLOYS	SMELTING	630	25.53	600 e	153.5	6,856	604.5
MANGANESE METAL	ELECTRO-LYTIC/ DO.	7 e	1.7	8.8 e	9.5 e	425 e	5.3
MANGANESE DIOXIDE	ELECTRO-LYTIC/ CHEMICAL/ DO	39 e	0.5	48.7 e	2	N.A.	38.5
MISCELLANEOUS (i.e. pure metal, manganese sulfate, potassium permanganate)	CHEMICAL	22 e	0.26	2.5 e	—	N.A.	21.74

Source: U.S. Bureau of Mines

e Arthur D. Little estimates based on internal and industry sources

N.A. Not Available

** Includes Mn ore converted to other Mn forms

- Existing and convertible domestic capacity is based on BuMines and ADL sources.
- Domestic supply are BuMines, industry, and ADL estimates.
- Non domestic supply is world supply (except for U.S.) and comes from BuMines, ADL, and industry estimates.
- Civilian demand D_3 is estimated by difference from the total.

This data is used to generate U.S. domestic demand/domestic capacity ratios in Table D-3 to perform the capacity vulnerability analyses for manganese.

Manganese Vulnerability Analysis

Capacity vulnerability analysis charts for the production of manganese ore, ferroalloys, metal and manganese dioxide for battery applications are shown in Figures D-5 through D-8, respectively. A comparison of all manganese forms evaluated are compiled on one vulnerability chart in Figure 2-9. A summary of the results of this manganese capacity analysis is shown in Table D-4. Manganese production capacity vulnerability is segmented into five categories --not vulnerable, slightly vulnerable, vulnerable, very vulnerable, and extremely vulnerable. This analysis indicates both peacetime and increased demand levels.

Manganese ore mining capacity falls in the "Extremely Vulnerable" category. Manganese ore mining capacity is the only process/product form that falls into this category. Ferroalloy smelting capacity for all demand levels falls into the "Slightly Vulnerable" category at this time. Although, as Figure D-3 indicates, domestic ferroalloy smelting capacity has been declining significantly for the last decade. This rate of capacity change, as reflected in Figure D-10 for manganese ferroalloy smelting since 1975, can help identify capacity trends. No historical production capacity data was obtained through public sources for manganese dioxide or manganese metal production. Domestic capacity to produce manganese metal falls in the "Not Vulnerable" category until three times peacetime demand level is achieved to shift 3X and 4X peacetime demand conditions into the "Slightly Vulnerable" category. All peacetime and increased demand conditions for manganese dioxide production capacity fall into the "Not Vulnerable" category, presently.

MANGANESE CAPACITY ANALYSIS SUMMARY

Capacity vulnerability analysis of manganese ore mining capacity has been designated as "Extremely Vulnerable" during peacetime and surge demand conditions. Even with the relatively low total critical U.S. domestic demand (D^*_T) of 28,000 tons in 1985 (includes all manganese use), domestic capacity is estimated to be only 40,000 tons per year.

Of the 698,000 tons of consumed manganese content in 1985, over 90% was used in the production of steel--primarily as ferroalloys. Only 4% of the total consumed manganese can be attributed to primary or secondary defense related end-use applications at peacetime demand levels (also primarily ferroalloys related). Existing domestic manganese ferroalloy capacity is

TABLE D-3

DOMESTIC DEMAND/ DOMESTIC CAPACITY RATIOS

	PEACE TIME		INCREASED DEMAND 2X	3X	4X
	$\frac{D_3}{C}$	$\frac{D^*}{C}$	$\frac{2D^*}{C}$	$\frac{3D^*}{C}$	$\frac{4D^*}{C}$
Ore Mining	3.75	0.7	1.4	2.1	2.8
Ferro Alloy	1.006	0.04	0.08	0.12	0.16
Manganese Metal	0.602	0.19	0.38	0.57	0.76
Manganese Oxide	0.79	0.01	0.02	0.03	0.04

FIGURE D-5
VULNERABILITY ASSESSMENT
Demand/Capacity Balance: Manganese Ore Mining

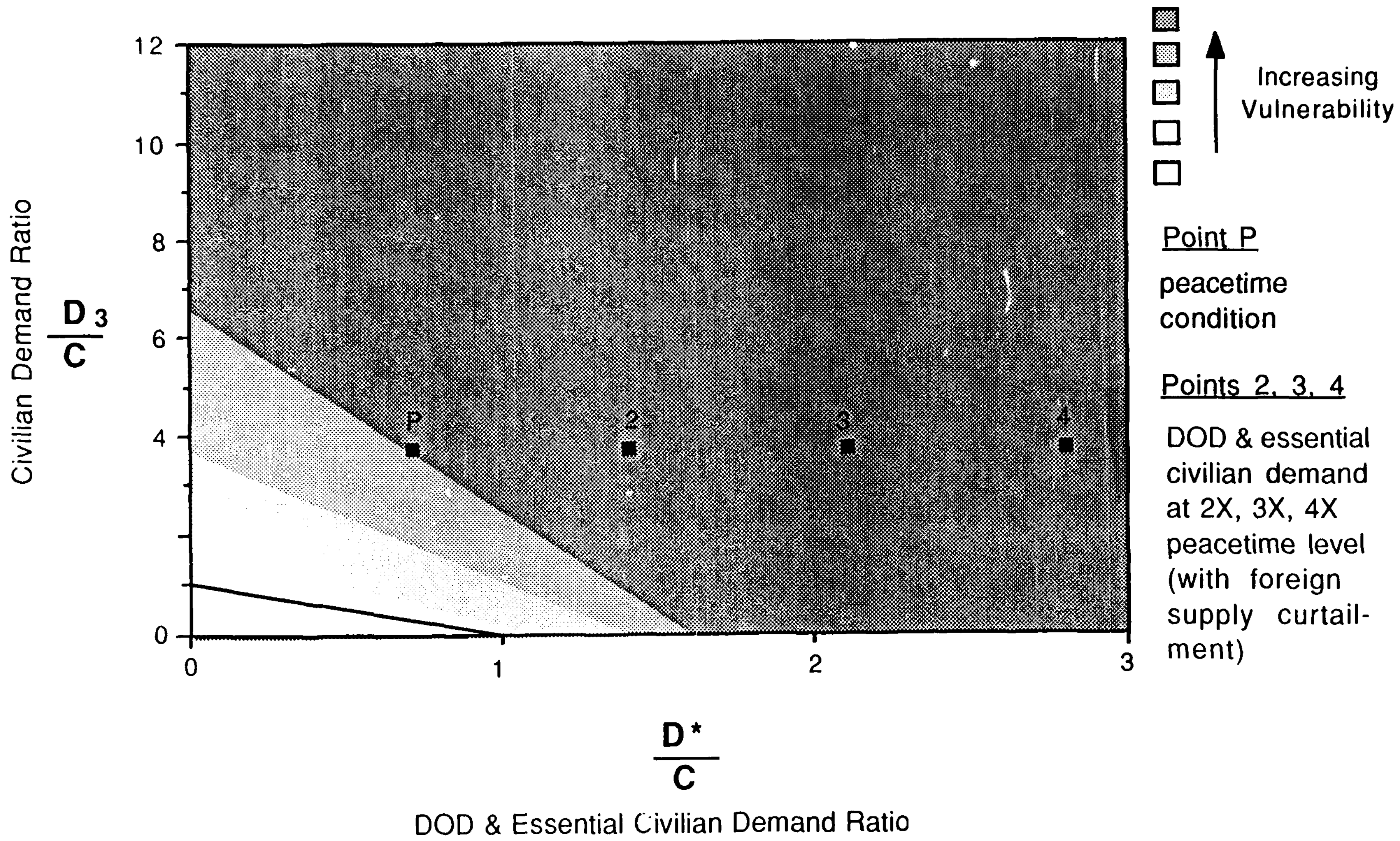


FIGURE D-6
VULNERABILITY ASSESSMENT
Demand/Capacity Balance: Manganese Ferro Alloy

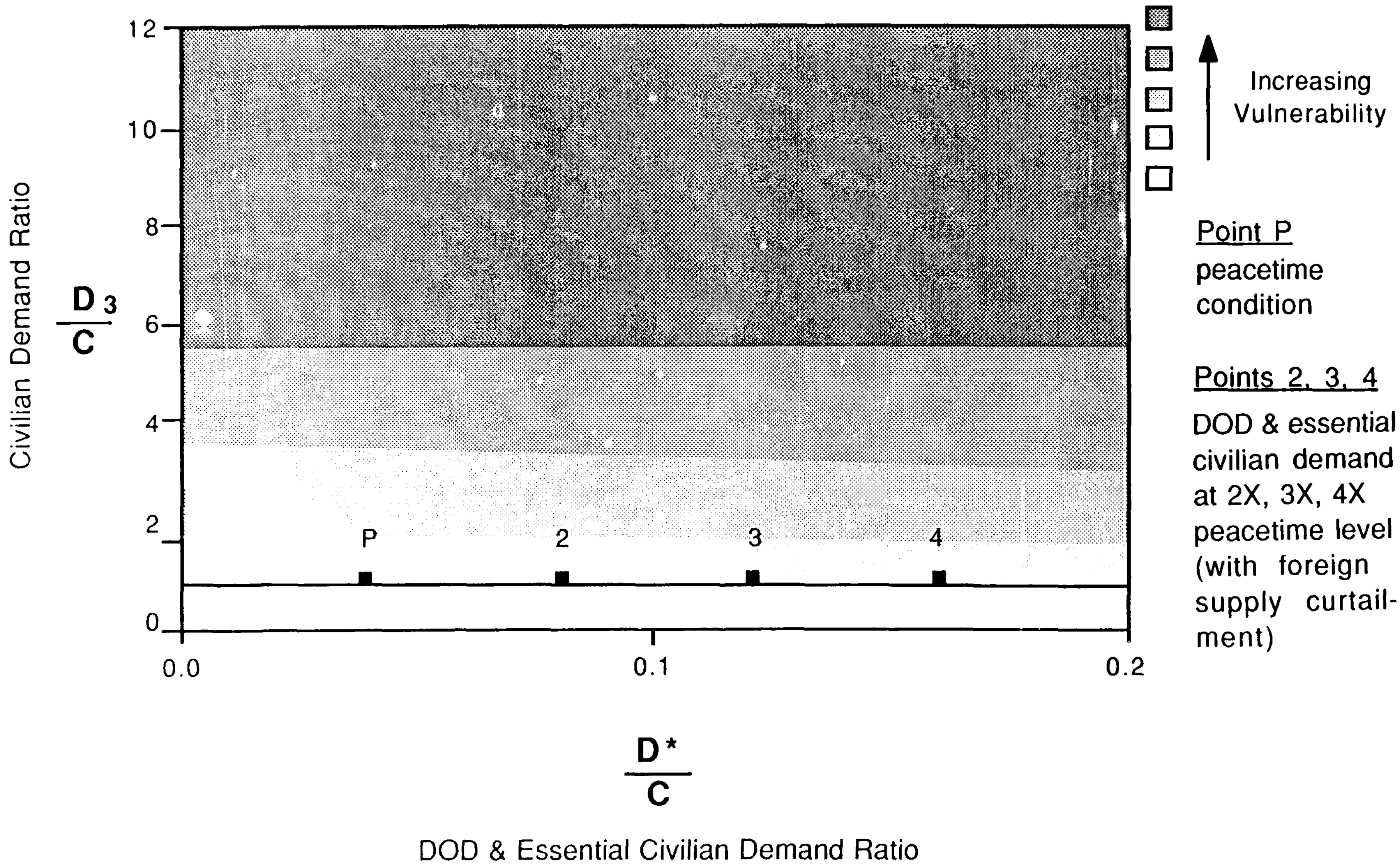


FIGURE D-7

VULNERABILITY ASSESSMENT:

Demand/Capacity Balance: Manganese Metal

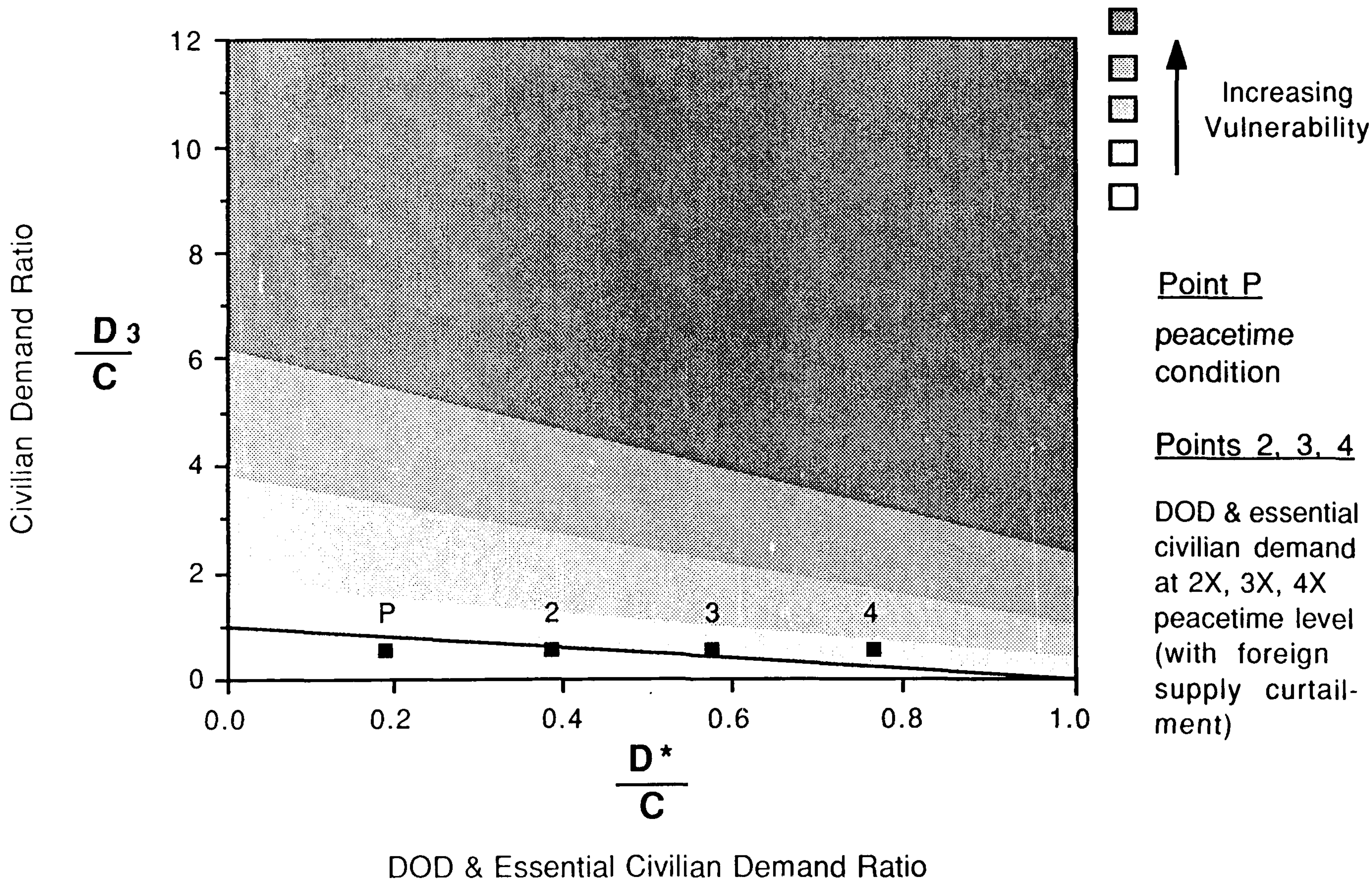


FIGURE D-8

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Manganese Dioxide

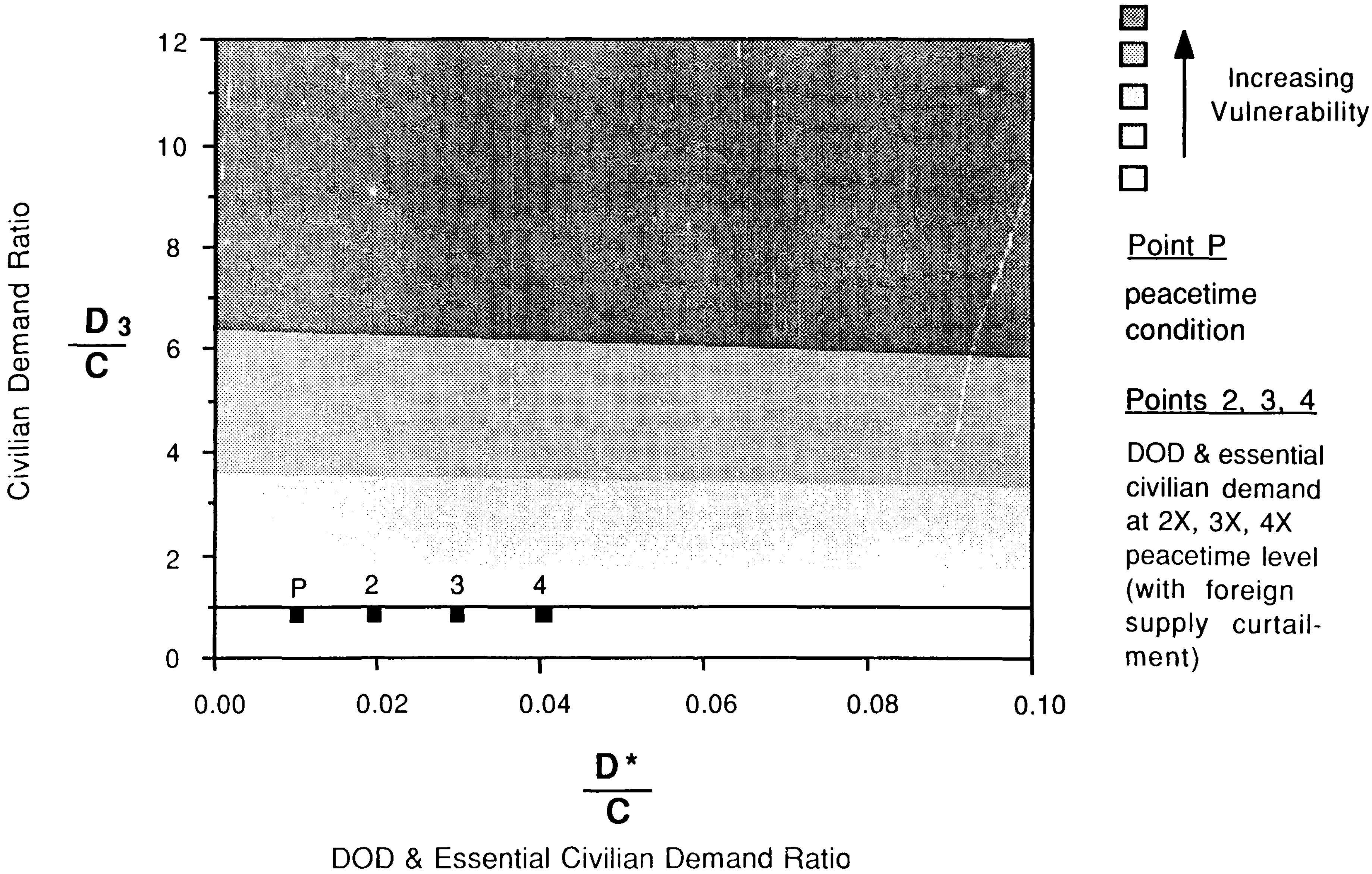


FIGURE D-9

VULNERABILITY ASSESSMENT:

Process Form Comparison for Manganese

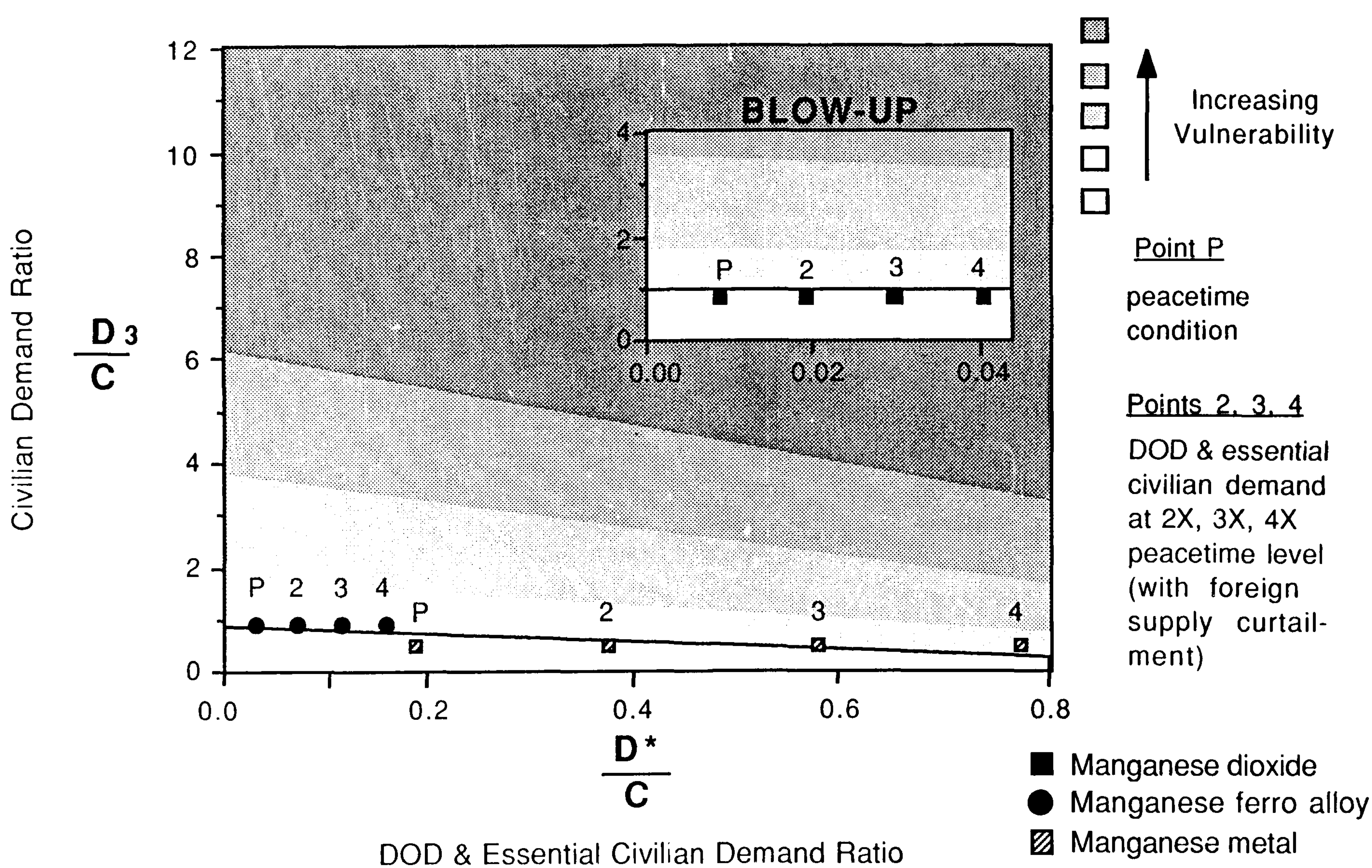


TABLE D-4

MANGANESE DOMESTIC CAPACITY ANALYSIS SUMMARY

RELATIVE VULNERABILITY INDEX

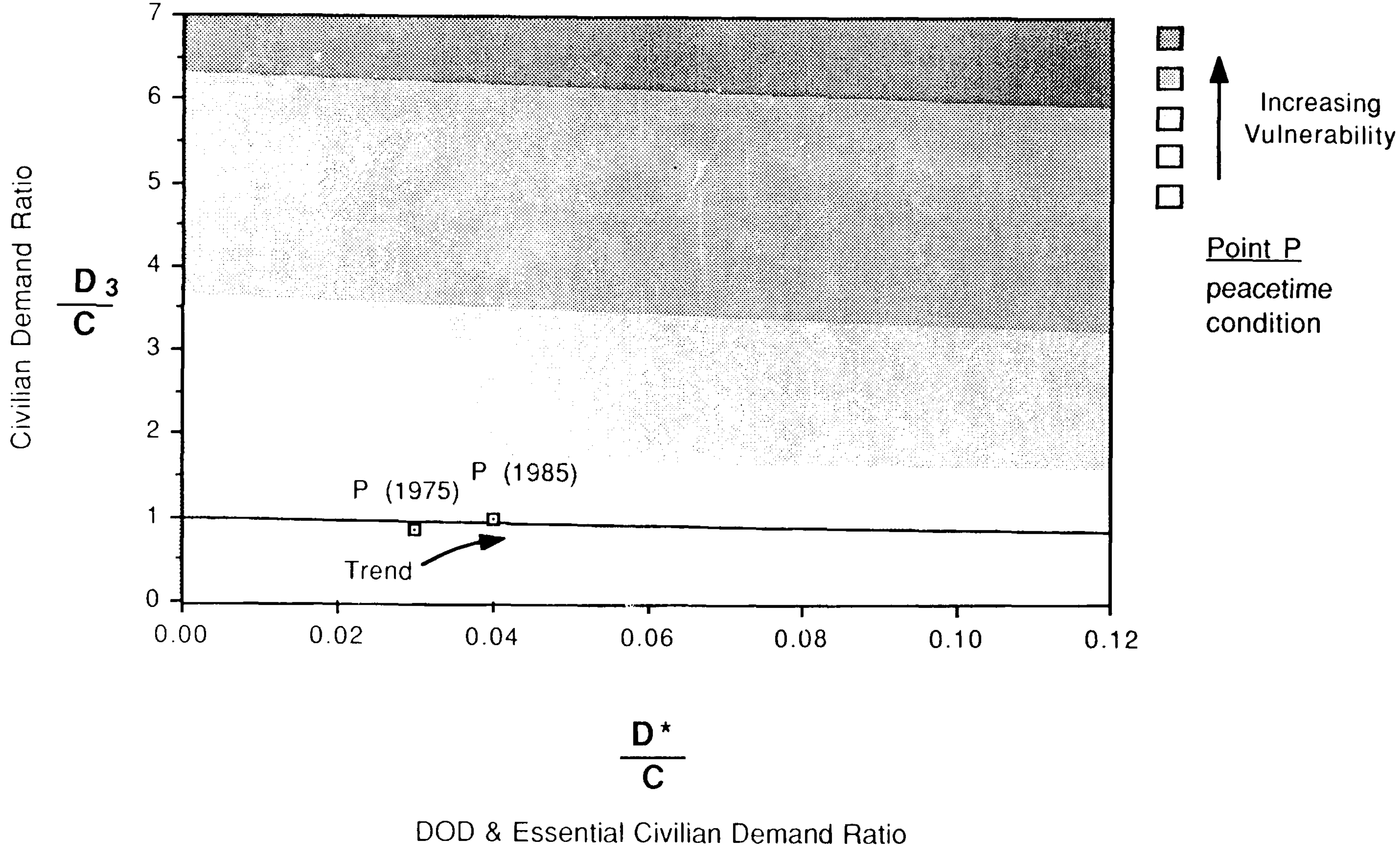
MANGANESE

INCREASING VULNERABILITY →

PROCESS	PRODUCT FORM	NOT VULNERABLE	SLIGHTLY VULNERABLE	VULNERABLE	VERY VULNERABLE	EXTREMELY VULNERABLE
MINING	ORE					P, 2, 3, 4
SMELTING	FERROALLOYS		P, 2, 3, 4			
ARC FURNACE ELECTROLYTIC	MANGANESE METALS	P,2	3,4			
ELECTROLYTIC CHEMICAL	MANGANESE DIOXIDE	P, 2, 3,4				

P - PEACETIME
2 - DEMAND (2X PEACETIME DEMAND)
3 - DEMAND (3X PEACETIME DEMAND)
4 - DEMAND (4X PEACETIME DEMAND)

FIGURE D-10
VULNERABILITY ASSESSMENT
Demand/Capacity Balance - Historical Trend For 1975-1985: Manganese Ferro Alloy



200,000 tons per year with estimated total domestic capacity (existing and convertible) being 600,000 tons per year. Capacity vulnerability analysis of ferroalloy production capacity has designated this product form as "Slightly Vulnerable" at peacetime and increased demand levels. Although, considering the percentage of total domestic manganese production ferroalloys represent and the rate of capacity decline vulnerability may increase dramatically in a short time period. The manganese product form flowsheet in Figure D-11 ties the various elements of manganese supply and demand together to emphasize the effects of capacity "pinchpoints" either downstream on the supply side or end-use on the demand side. For example, the manganese ore mining pinchpoint will affect all downstream unit operations, processes and demands. Manganese ferroalloys and metal basically affect the production capacity of steels and other alloys. Numbers in each intermediate product form "oval" indicate the estimated percentage of that form which is foreign supplied.

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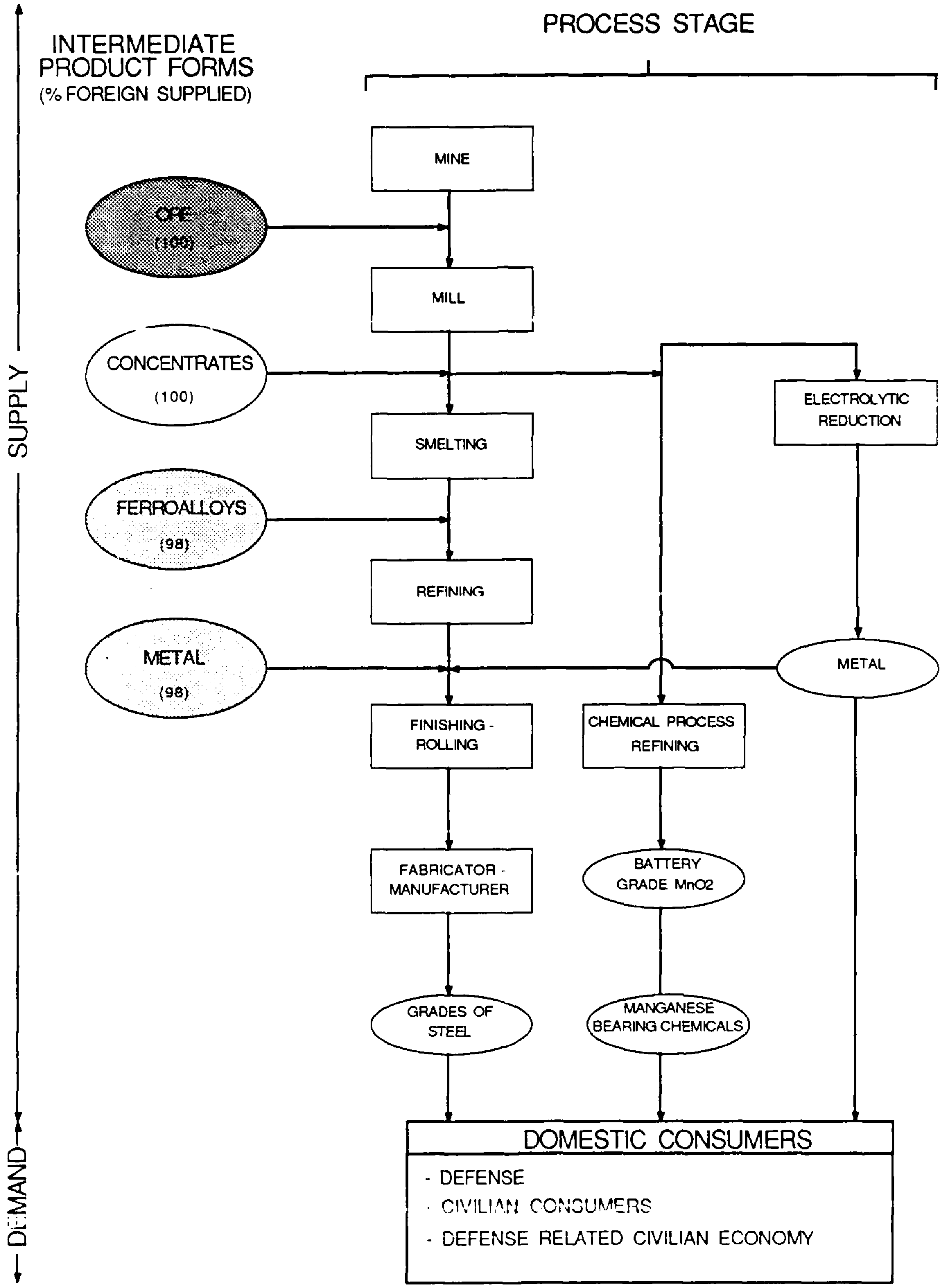
FIGURE D-11
MANGANESE PRODUCT FORM FLOWSHEET



APPENDIX E

CHROMIUM INDUSTRY STRUCTURE

Overview

Chromium has a wide range of uses in the metallurgical, chemical, and refractory industries. It is one of the Nation's most important strategic and critical materials. Chromium use in iron, steel, and nonferrous alloys enhances hardness and resistance to corrosion and oxidation. The use of chromium to produce stainless steel and nonferrous alloys are two of its more important applications. Other applications are in alloy steel, plating of metals, pigments, leather processing, catalysts, and refractories.[1]

Because the United States has no chromium reserves and limited resources, domestic chromium supply has been of concern during every national military emergency since World War I. World chromite (i.e. chromium ore or concentrates from ore) resources, mining capacity, and increasingly ferrochromium production capacity are concentrated in the Eastern Hemisphere.

Although chromium is found in various minerals, chromite is the sole source of chromium used commercially today. Production from domestic sources has been sporadic in the last 30 years, generally not able to economically compete with foreign sources.

Geographic Distribution

Reported world production of chromite ore and concentrate in 1983 came from 18 countries. About 46% of the production was by countries with centrally controlled economies: Albania, Cuba, U.S.S.R., and Vietnam. Other countries such as Greece, Turkey, India, and Finland have some production that is state controlled. However, a large share of the world's chromite production is privately owned, primarily large mining and resource companies.[1]

Foreign chromium ferroalloy production operations parallel those of the United States in that producers are generally not owned by steel manufacturers; however, some producers are state owned. Historically, the more highly developed countries have been the largest producers of chromium alloys, but the current trend is for countries where the natural resources reside to install their own furnace capacity for vertical integration into ferroalloy production.

Only Outokumpo Oy of Finland and Middleburg Steel & Alloys Holdings (Pty.) Ltd. of the Republic of South Africa are vertically integrated companies from chromite mining to smelting through stainless steel production.[1]

Grades and Specifications

Of the many minerals that contain chromium, chromite mineral is the only ore. The chromic oxide (Cr_2O_3) content of pure chromite by weight is 67.9%; chromium content, 46.5%. Chromite ore rarely contains more than 50% chromic oxide. and other minerals, such as silica (SiO_2), are present. Chromite ore and concentrates derived from chromite ore are classified, for

purposes of tax collection, into three categories. The grade of chromite containing no more than 40% chromic oxide is used in the refractory industry. The grade containing more than 40% chromic oxide but less than 46% is used by the refractory, chemical, and metallurgical industries. The grade with 46% or more chromic oxide is used by the metallurgical and chemical industries.

For most metallurgical applications, chromium is used in the form of ferrochrome (an alloy containing chrome, iron, and carbon) or ferrochromium-silicon (ferrochrome with silicon). Chromium metal and ferroalloys are made in a number of grades some of which are shown in Table E-1 (the balance of composition over what is shown is iron).

Chromium metal in its purest form (99.996% chromium) is produced in limited quantities by vapor deposition from anhydrous chromium iodide. Commercial chromium metal is produced either by electrolysis of an electrolyte containing chromium or by aluminothermic reduction of pure chromic oxide.[1]

High-carbon ferrochromium, low-carbon ferrochromium, and ferrochromium-silicon are additives to produce stainless, alloy, and tool steels and cast irons. High-carbon ferrochrome is used where the control of carbon in the steel is required after ferroalloy additions or where carbon content is not a problem. Most stainless steel is now produced using argon-oxygen-decarburization (AOD) or a similar process. This process is able to remove carbon from the molten steel without endangering the alloying element content, such as chromium. The AOD process is able to accept cheaper, low-grade, high-carbon ferroalloys, in particular ferrochrome for stainless steel production.

CHROMIUM INDUSTRIAL APPLICATIONS

Overview

Chromium is one of modern industry's essential and versatile elements. Commercial forms of primary chromium, chromite, ferrochromium, and chromium metal are consumed in the production of ferrous and nonferrous alloys, refractories, and chemicals.

Ferrous alloy production, mainly stainless steels, accounts for most chromium consumed. Chromium is also a constituent of a variety of alloy steels, cast irons, and nonferrous alloys. Chromium's functioning in these products is to improve mechanical properties, impart special electrical properties, or enhance abrasion resistance.

Stainless steel, by definition, contains between 12% and 36% chromium. Ferrochromium and stainless steel scrap are the major sources of chromium in stainless steel. Chromium provides passivation in iron-base alloys. A minimum of 12% chromium is required to reduce the reactivity of chemically active ferrous metal surfaces.[1]

Chromium-containing tool steels have a content range of 1% to 12% chromium. In high-speed steels, chromium plays in important role in the hardening mechanism. In high-carbon, high-chromium, cold-worked steels, chromium

TABLE E-1

COMPOSITION OF TYPICAL CHROMIUM FERROALLOYS AND CHROMIUM METAL

(Composition, Percent)

Type	Grade	Chromium	Carbon	Silicon	Sulfur[1]	Phosphorus[1]	Nitrogen
High-carbon ferrochromium	A	52-58	6.0-8.0	6	0.04	0.03	- - -
	B	55-64	4.0-6.0	8-14	0.04	0.03	- - -
	C	62-72	4.0-9.5	3	0.06	0.03	- - -
Low-carbon ferrochromium	A	60-67	0.025	1-8	0.025	0.03	- - -
	B	67-75	0.025	1	0.025	0.03	- - -
	C	67-75	0.05	1	0.025	0.03	- - -
	D	67-75	0.75	1	0.025	0.03	- - -
	E	67-72	0.02	2	0.03	0.03	- - -
	F	67-72	0.01	2	0.03	0.03	- - -
	G	63-68	0.05	2	0.03	0.03	5-6
	- - -	62-70	0.10	1	0.025	0.03	1-5
Ferrochromium-silicon	A	34-38	0.06	38-42	0.03	0.03	- - -
	B	38-42	0.05	41-45	0.03	0.03	- - -
Chromium metal	A	[2]99.0	0.05	0.15	0.03	0.01	- - -
	B	[2]99.4	0.05	0.10	0.01	0.01	- - -

[1] Maximum, except where range of values indicating minimum and maximum appears.

[2] *Minimum.*

Source: 1982 Annual Book of ASTM Standards. Part 2.

contributes hardness and wear resistance. In hot-worked and special purpose steels, chromium contributes to hardenability, hardness, and wear resistance.

Most full alloy steels contain from 0.5% to 9% chromium, but some grades contain up to 28% chromium. The role of chromium in full alloy steels is to provide hardenability; toughness; case and core hardenability; corrosion and oxidation resistance; fatigue, abrasion, and sag resistance; and impact, creep, and stress rupture strength.[1]

Cast irons contain from 0.5% to 30% chromium. In cast irons, the role of chromium is to provide hardenability, hardness, toughness, dimensional stability, and corrosion, abrasion, impact, and wear resistance.

Chromium is an important and widely used alloying element in nonferrous alloys, including those based on nickel, iron-nickel, cobalt, aluminum, titanium, and copper. In alloys based on nickel, iron-nickel, and cobalt, chromium is used primarily to confer oxidation and corrosion resistance. In alloys of aluminum, titanium, and copper, chromium is used to control microstructure. Chromium alloying additions to aluminum serve to control recrystallization behavior and thereby help to achieve consistent product performance.

Chromium pigments represent the largest use of chromium in the chemical industry. Sodium dichromate (the primary base material for manufacture of chromium chemicals) is used to manufacture chrome green, chrome oxide green, chrome yellow, molybdenum orange, and zinc chromate pigments. These paints are used for corrosion inhibition undercoatings. The familiar chromium plating used in automobile trim, appliances and other consumer goods is produced from chromium chemicals. Other uses that take advantage of the special properties of these chemicals are leather tanning, metal treatment (corrosion inhibitor), drilling muds, textile dyes, catalysts, and wood and water treatment. Chromic oxide is also used to make refractories and chromium metal.

In the refractory industry, chromite is used to make refractory brick and mortars, and ramming aid gunning mixes. Chromium-containing refractory bricks may contain up to 100% chrome (chromite granules). Chromite is blended with magnesite to produce chrome-magnesite (greater than 50% by weight chrome) and magnesite-chrome (greater than 50% by weight magnesite) bricks. These bricks are chemically bonded (unburned), burned, or fusion cast. Chromic oxide, chromium carbides, and chromium borides are also used in refractories but to a much lesser extent than chromite mineral. The major application of chromite refractories is in iron and steel processing, nonferrous alloy refining, glassmaking, and cement processing. Chromite sand is used in refractories to enhance thermal shock and slag resistance volume stability, and structural strength.

Substitution Technology

According to a recent study [2], about 30% of domestic chromium use could be saved by functionally acceptable chromium-free substitutes currently available. An additional estimated 40% could be saved after 10 years of research and development. Thirty percent of domestic use is considered

irreplaceable, where no functionally acceptable chromium-free substitutes are available.

Of the ferrous alloys, stainless steel accounts for the major amount of chromium use. The greatest possibility for substitution there is to substitute a lower chromium stainless for a higher chromium stainless. For some applications, other base metal alloys like aluminum or titanium alloys may be substituted for stainless steel. Four strategies useful in identifying stainless steel substitution possibilities are (1) to replace chromium in excess of 12% by other alloying elements, (2) to replace the stainless steel by an alloy or stainless steel that contains less chromium, (3) to use a higher chromium content alloy that will extend product life enough to result in a net chromium savings, and (4) to use a surface modification technique, such as cladding, plating, or coating. Which of these strategies results in a useful stainless steel substitution depends on the end-use requirements.[1]

As a class of material, ferrous alloys other than stainless steel do not have a specified minimum chromium content; however, many particular steel alloys do specify chromium contents. Chromium is used in some grades of alloy steels, tool steels, and cast irons. In full alloy steels, boron, manganese, molybdenum, nickel, and silicon may substitute for chromium. In tool steels, chromium is essential and irreplaceable.

In the refractories industry, chromite is mixed with refractory magnesia to produce chrome-magnesite refractory bricks.

Chromium's two principal chemical uses - pigment and plating - are more susceptible to substitution than the metallurgical applications. Although chromium pigments have a well-established market, substitutes such as cadmium yellow, organic yellow, and yellow iron oxide pigments for chrome yellow are available, but with sacrifice in properties desired.

Chromium is used for both hard and decorative plating. There is no satisfactory alternative for chromium in industrial hard plating, but in decorative plating, nickel, cadmium, and zinc may provide functional substitutes in some end-use applications.[1]

CHROMIUM SUPPLY/DEMAND RELATIONSHIPS

Breakdown of U.S. Chromium Consumption by Product Form-1985

U.S. chromium consumption is segmented into chromium product forms in Figure E-1. In 1985, the primary usage of chromium was in the form of 285,000 tons of chromium metal and ferroalloys (75.4% of total consumption) for metallurgical industry end-use. Chromium ore (chromite) and chromium bearing chemicals comprise 93,000 ton or around one-quarter of total demand.

Chromium: Supply/Demand Relationship-1985

A world supply/U.S. domestic demand relationship for chromium is shown in Figure E-2. As indicated, world production of chromite ore is estimated to

FIGURE E-1

Total U.S. Chromium Consumption By Form - 1985
(Thousand Short Tons)

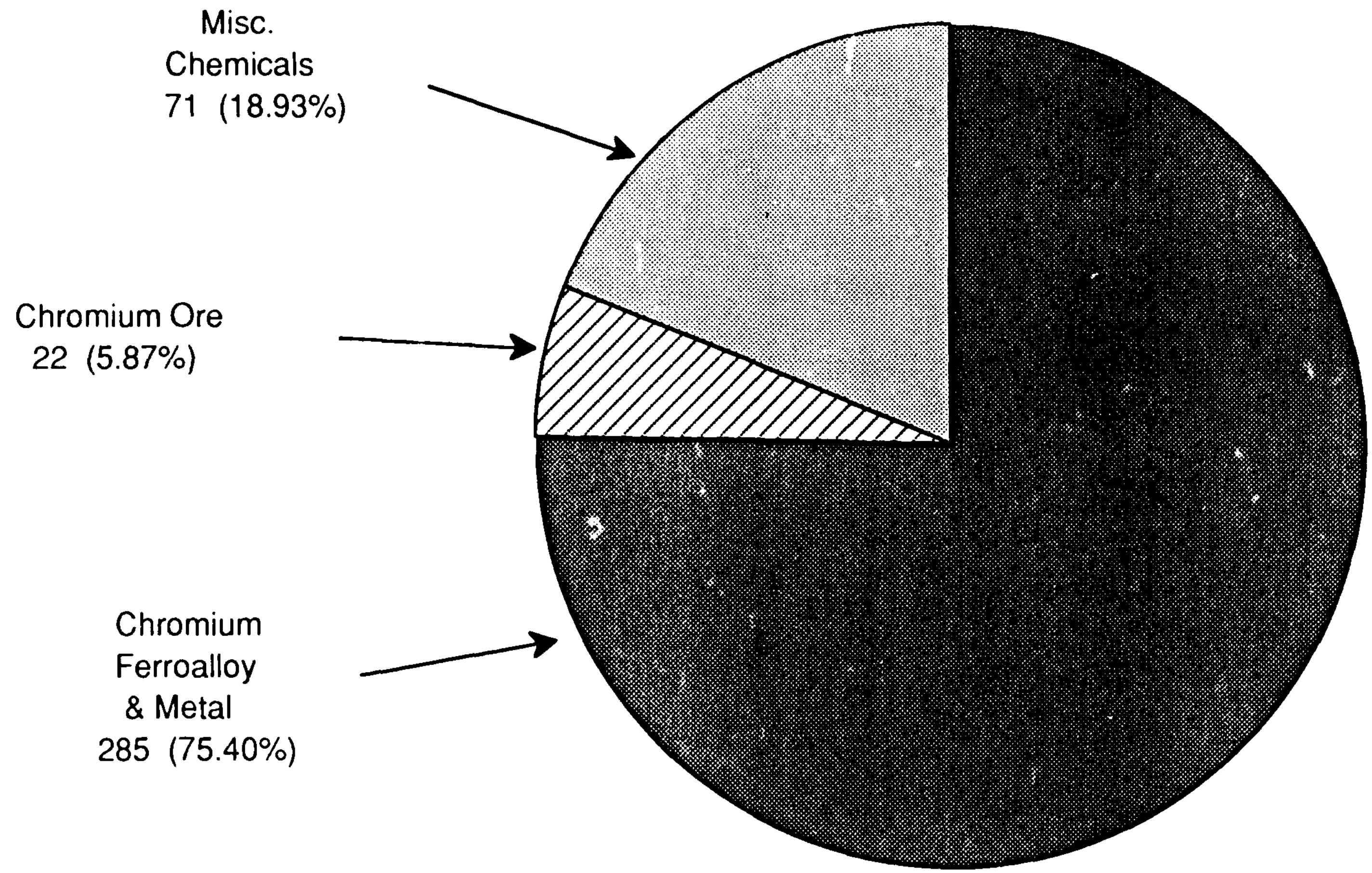
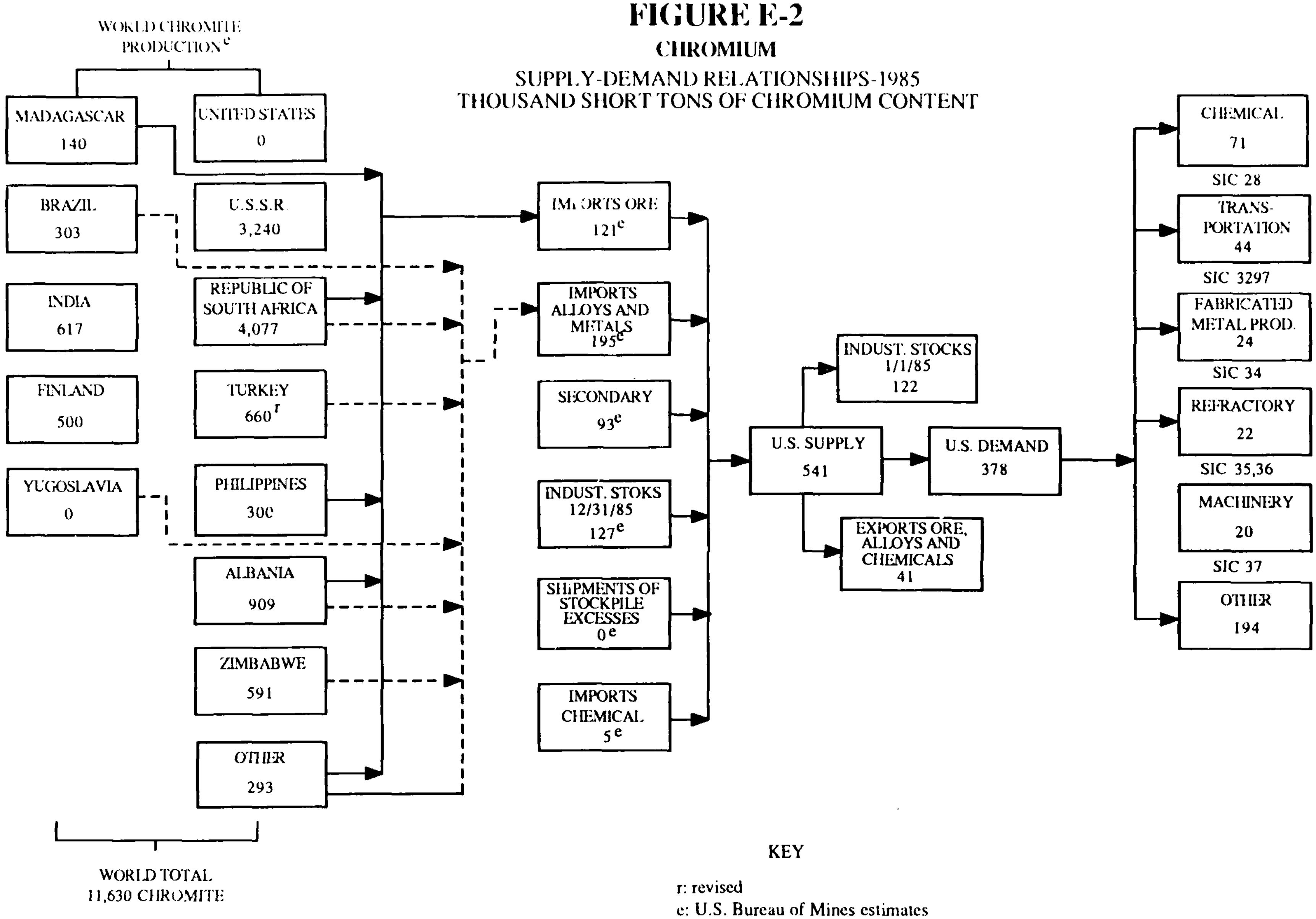


FIGURE E-2

CHROMIUM

SUPPLY-DEMAND RELATIONSHIPS-1985
THOUSAND SHORT TONS OF CHROMIUM CONTENT



KEY

r: revised
e: U.S. Bureau of Mines estimates
SIC: STANDARD INDUSTRIAL CLASSIFICATION
- - - ALLOY IMPORTS
—— CHROMITE IMPORTS

Source: U.S. Bureau of Mines and Arthur D. Little, Inc. estimates based on internal and industry sources.

be 11.6 million tons of which the U.S. had no contribution in 1985. Imports of alloys and metal totalled 195,000 tons for 1985, which was 61% of total imports. Of the total chromium demand (378,000 tons) in 1985, around three-quarters was consumed in a metallurgical application for four economic sectors - transportation, fabricated metal products, machinery and other.

Chromium Domestic Supply/Demand Relationship: 1975-1985

A historical perspective of the United States dependence on foreign capacity to supply domestic demand is shown in Figure E-3. U.S. domestic production of primary and secondary chromium metal generally meets 30% or less of overall demand. There was no commercial domestic chromium ore mining production in 1985.

Domestic Producers of Chromium Product-1986

U.S. producers of chromium products are listed in Table E-2. The major products of chromium are alloys, chemicals, chromium ore, and metal.

Elkem AS, Macalloy, Inc., Metallurg, Inc., Moore McCormack Resources, Inc., Satra Concentraks, Inc., and S&W Alloy, Inc. are the domestic producers of chromium metal and alloy.

Refractory products are produced by Basic, Inc., Corhart Refractories Co., General Refractories Co., Dresser Industries, Inc., National Refractories & Minerals Corp., and North American Refractories Co.

Chromite bearing chemicals such as sodium dichromate are produced by Occidental Chemicals Corp. and American Chrome & Chemicals, Inc.

Recycle Flow for Chromium

A chromium scrap flow diagram depicting the general recycle flows are shown in Figure E-4. Scrap chromium metal accounted for around 23% of primary production in 1983. Only stainless steel and high alloy steels scrap are sizeable sources of recycle supply. Between 35% and 45% of stainless steel production in any given year is recycled as home scrap. Intermediate collection and sorting of prompt industrial and old scrap is generally the case. Where prompt industrial scrap generally has a relatively short cycle time (months) obsolete scrap (particularly stainless and heat-resisting steels) may be out of circulation for 25 years.[3]

The automobile industry is the largest single source of recovered obsolete stainless scrap, providing one-third of the total. Other sectors with estimated large amounts of unrecovered stainless scrap include: appliances, utensils and cutlery, machinery, industrial equipment and tools, other commercial equipment. Smaller amounts of chromium are also recovered from superalloys and cast heat- and corrosion-resistant alloys.

Estimated DOD-Related and Civilian Demand

Critical to this analysis of capacity/demand balance is the segmentation of total U.S. domestic demand (D_t) for chromium into its three components:

FIGURE E-3
Chromium Metal Domestic Supply-Demand Relationship, 1975-1985

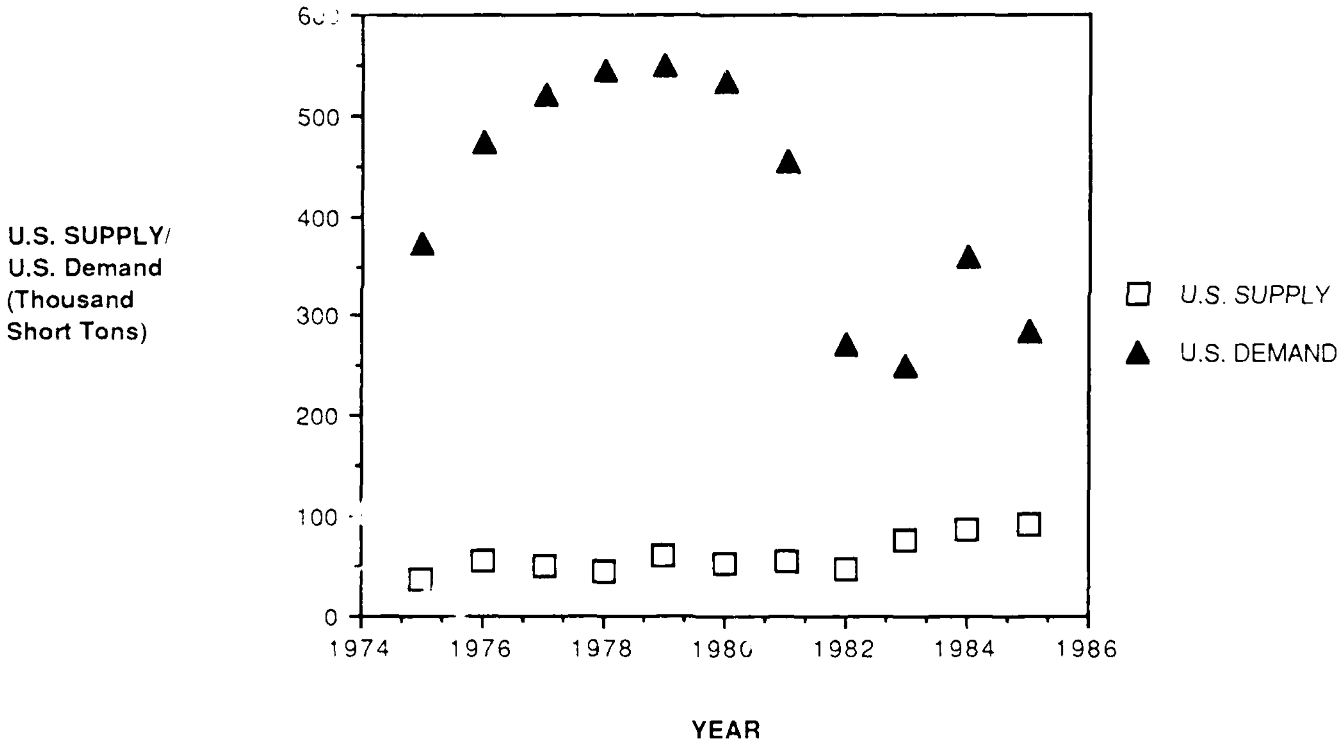


TABLE E-2

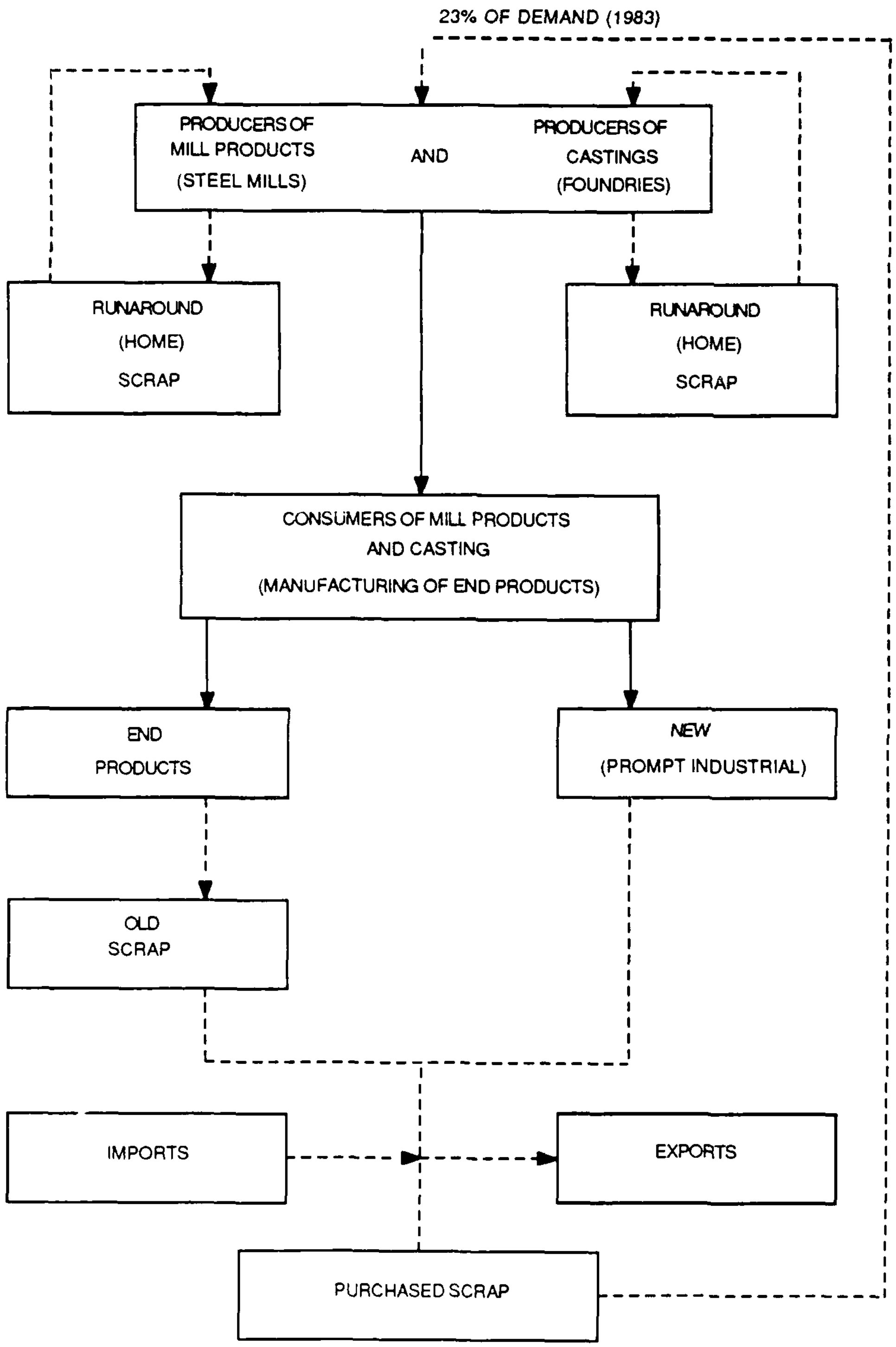
DOMESTIC PRODUCERS OF CHROMIUM PRODUCTS IN 1987

Product Form	Company	Plant Location
Metallurgical:	Elkem AS, Elkem Metals Co.	Marietta, OH, and Alloy, WV.
	Macalloy Inc.	Charleston, SC.
	Metallurg Inc., Shieldalloy Corp.	Newfield, NJ.
	Moore McCormack Resources Inc., Globe Metallurgical Inc.	Beverly, OH.
	Satra Concentrates Inc.	Steubenville, OH.
	SKW Alloys Inc.	Calvert City, KY, and Niagara Falls, NY.
Refractory:	Basic Inc.	Maple Grove, OH.
	Corhart Refractories Co. Inc.	Pascagoula, MS.
	General Refractories Co.	Lehi, UT.
	Harbison-Walker Refractories, a division of Dresser Industries Inc.	Hammond, IN
	National Refractories & Minerals Corp.	Moss Landing, CA, and Columbiana, OH.
	North American Refractories Co. Ltd.	Womelsdorf, PA.
Chemical:	American Chrome & Chemicals Inc.	Corpus Christi, TX.
	Occidental Chemicals Corp.	Castle Hayne, NC.

Source: U.S. Bureau of Mines.

FIGURE E-4

SCRAP-FLOW DIAGRAM FOR CHROMIUM



------ Scrap Flow

Source: U.S. Bureau of Mines

civilian demand (D_3), essential civilian demand (D_2), and estimated DOD demand (D_1). Analysis by Arthur D. Little, Inc., for FEMA using the INFORUM database converted domestic chromium demand in U.S. dollars to estimated tons of chromium content for DOD and essential civilian end use. This analysis for chromium, an example of which is in Appendix A, further segmented domestic chromium demand into end-use economic sectors--chemicals, transportation, fabricated metal product, refractory, machinery, and other.

Chromium Form Consumed for Each Economic Sector

In order to analyze the capacity/demand balance for a particular material process/product form, the percentage of various product forms being supplied to particular end-use economic sectors must be estimated. In the case of chromium, there were three process/product forms to be analyzed:

- Mining/Ore
- Smelting or Reduction/Metal (including Ferroalloys)
- Chemical/Chemicals

Segmentation of total domestic demand in 1985 for each economic sector by chromium product form is shown in Figure E-5. In addition, the segmentation of total domestic demand into estimated DOD & essential civilian demand (D*) and civilian demand (D_3) allows the computation of chromium domestic demand on a process/product form basis also shown in Figure E-5.

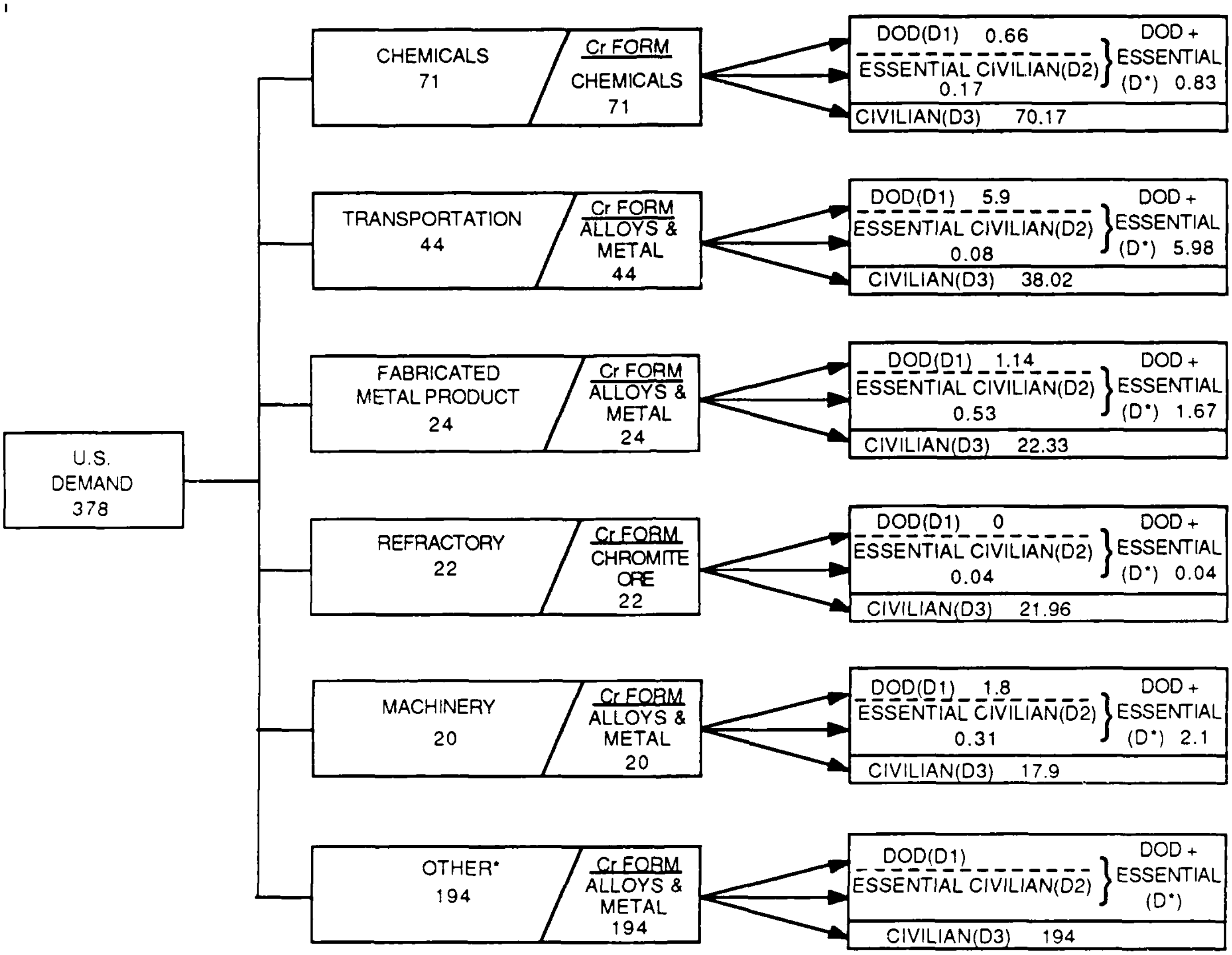
CHROMIUM CAPACITY ANALYSIS

Chromium vulnerability analysis data segmentation of total U.S. domestic chromium demand into estimated DOD and essential civilian demand categories in Appendix A, breakdown of U.S. chromium demand by process/product form in Figure E-5 along with supply and capacity estimates are compiled and consolidated in Table E-3. This data is used to generate U.S. domestic demand/domestic capacity ratios in Table E-4 to perform the capacity vulnerability analyses for chromium.

Chromium Vulnerability Analysis

Capacity vulnerability analysis charts for the production of chromium ore, chromium ferroalloys and metal, and chromium chemicals are shown in Figure E-6 through Figure E-8, respectively. It should be noted that these figures are "blowups" of the extreme left-hand side of the vulnerability figures (the horizontal axis ranges from zero to only 0.05). A comparison of all chromium forms on one vulnerability chart is shown in Figure E-9. Chromium production capacity vulnerability has been segmented into five categories--not vulnerable, slightly vulnerable, vulnerable, very vulnerable, and extremely vulnerable as indicated in Table E-5. Chromium ore mining capacity falls into the "very vulnerable" category with only 5,000 annual tons estimated capacity. Chromium metals and ferroalloys fall into the "slightly vulnerable" category basically due to the relatively high civilian demand (275,000 tons) compared to estimated annual capacity

FIGURE E-5
U.S. CHROMIUM DEMAND 1985
BREAKDOWN
(THOUSAND SHORT TONS)



*Assume Cr form as alloys & metal going to civilian sector (D3)

Source: U. S. Bureau of Mines and Arthur D. Little, Inc.
Estimates based on Inforum Data

TABLE E-3
CHROMIUM VULNERABILITY INDEX DATA (1985)

Thousand Short Tons per Year
(Contained Chromium)

CHROMIUM		TOTAL Cr DEMAND (D_T)	DOD & ESSENTIAL CIVILIAN DEMAND (D^*)	EXISTING & CONVERTIBLE DOMESTIC CAPACITY (C)	DOMESTIC SUPPLY (S)	NON-DOMESTIC SUPPLY	CIVILIAN DEMAND (D_3)
PRODUCT FORM	PROCESS STAGE						
ORE	MINING	22	0.04	5 †	0.0	3650	21.96
CHROMIUM FERROALLOY AND METAL	SMELTING/ ELECTROLYTIC REDUCTION	285	9.75	187 [e]	110	3268	275.25
MISCEL-LANEOUS	CHEMICAL	71	0.83	88 [e]	N.A.	N.A.	70.17

Source: U.S. Bureau of Mines

e: Arthur D. Little estimates based on internal and industry sources.

N.A.: Not Available

† Capacity estimate calculated assuming 1 year lead time and data from "Chromium Availability - Domestic"

TABLE E-4

CHROMIUM DOMESTIC DEMAND/ DOMESTIC CAPACITY RATIOS

	PEACE TIME		INCREASED DEMAND 2X	INCREASED DEMAND 3X	INCREASED DEMAND 4X
	$\frac{D_3}{C}$	$\frac{D^*}{C}$	$\frac{2D^*}{C}$	$\frac{3D^*}{C}$	$\frac{4D^*}{C}$
Ore Mining	4.39	.008	.016	.024	.032
FerroAlloy and Metal	1.47	0.052	0.104	0.156	0.208
Chemicals	0.79	.009	.018	.027	.0326

FIGURE E-6
VULNERABILITY ASSESSMENT
Demand/Capacity Balance: Chromium Ore Mining

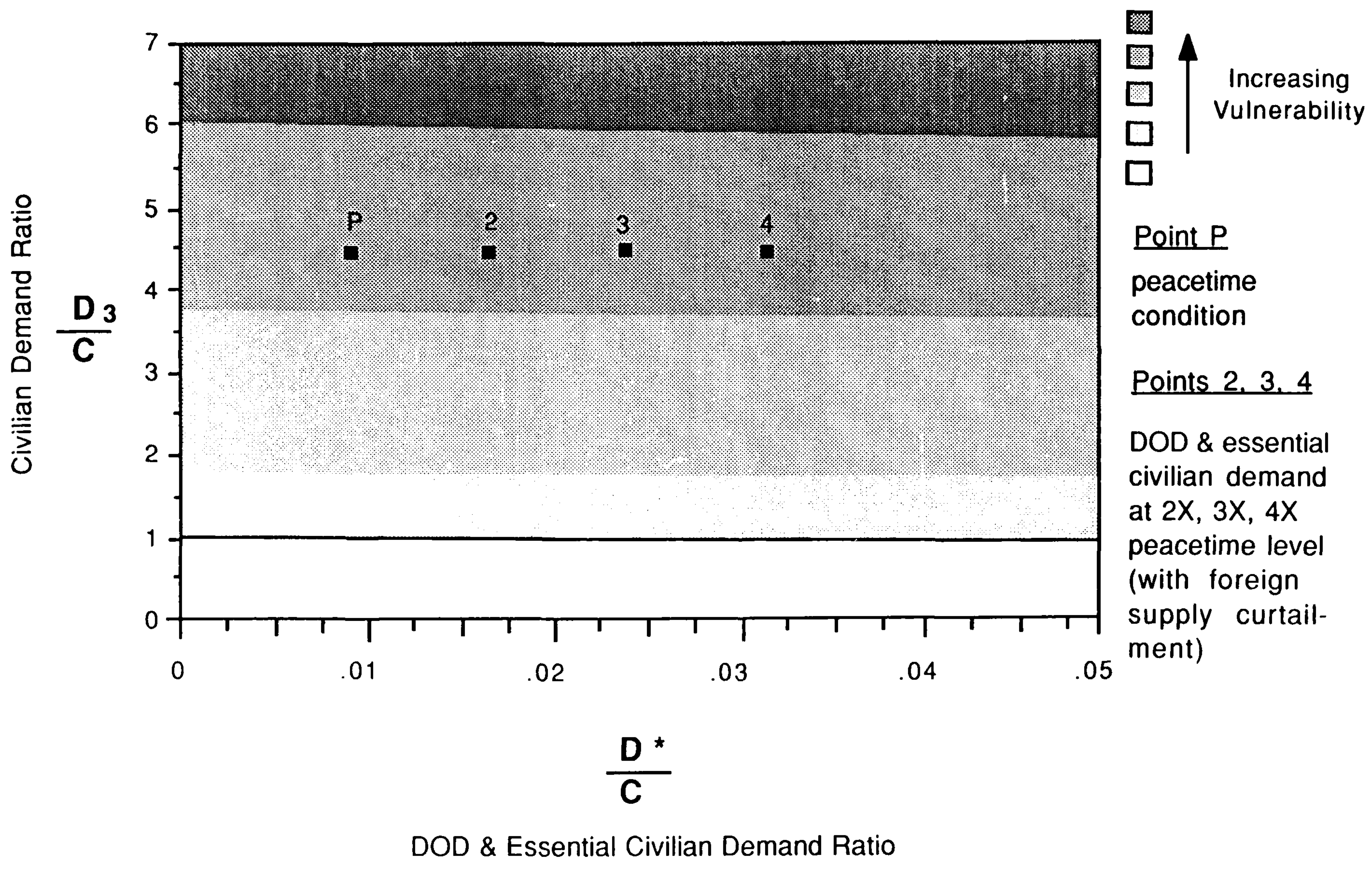


FIGURE E-7
VULNERABILITY ASSESSMENT
Demand/Capacity Balance: Chromium Ferro Alloy and Metal

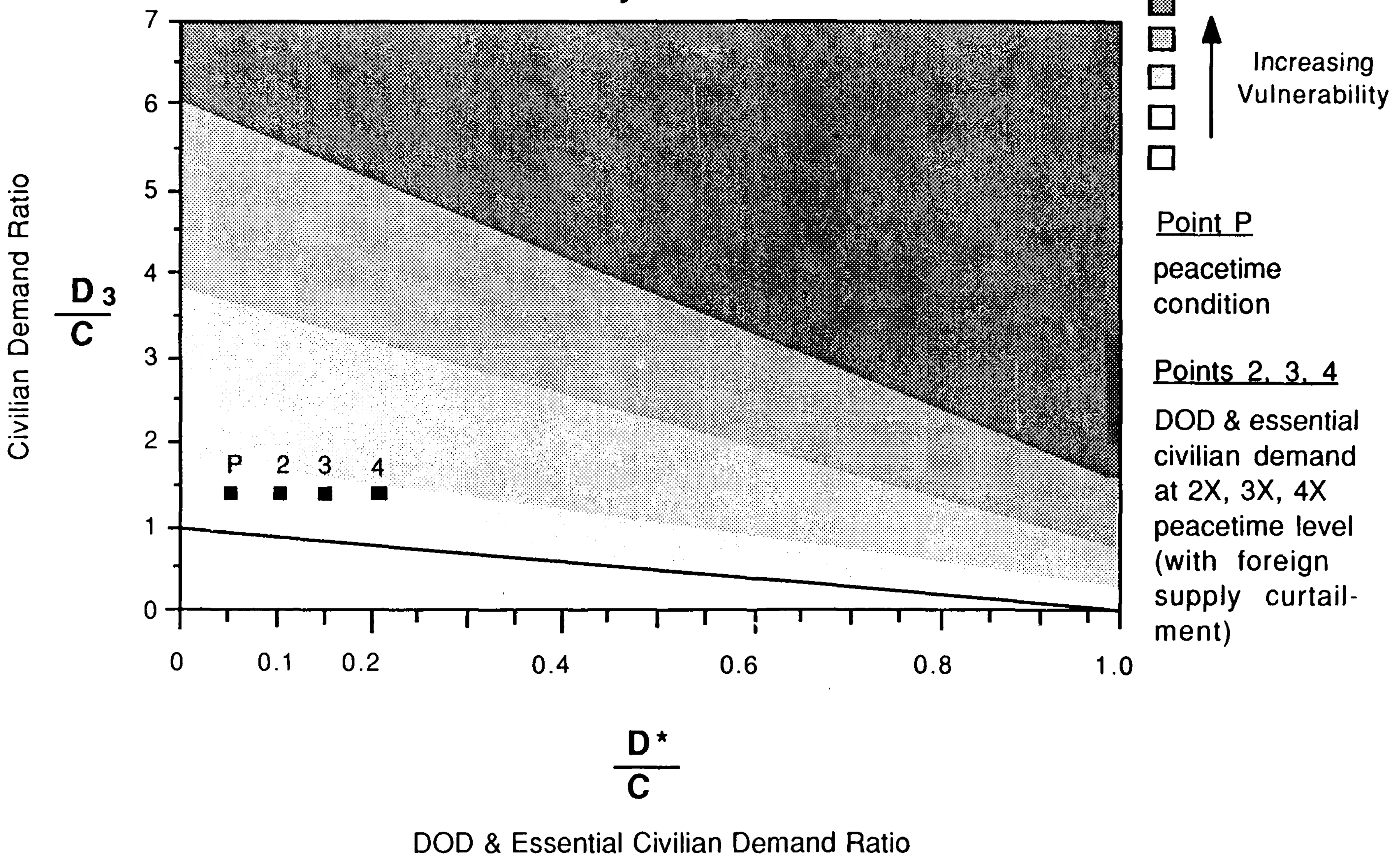


FIGURE E-8

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Chromium Chemicals

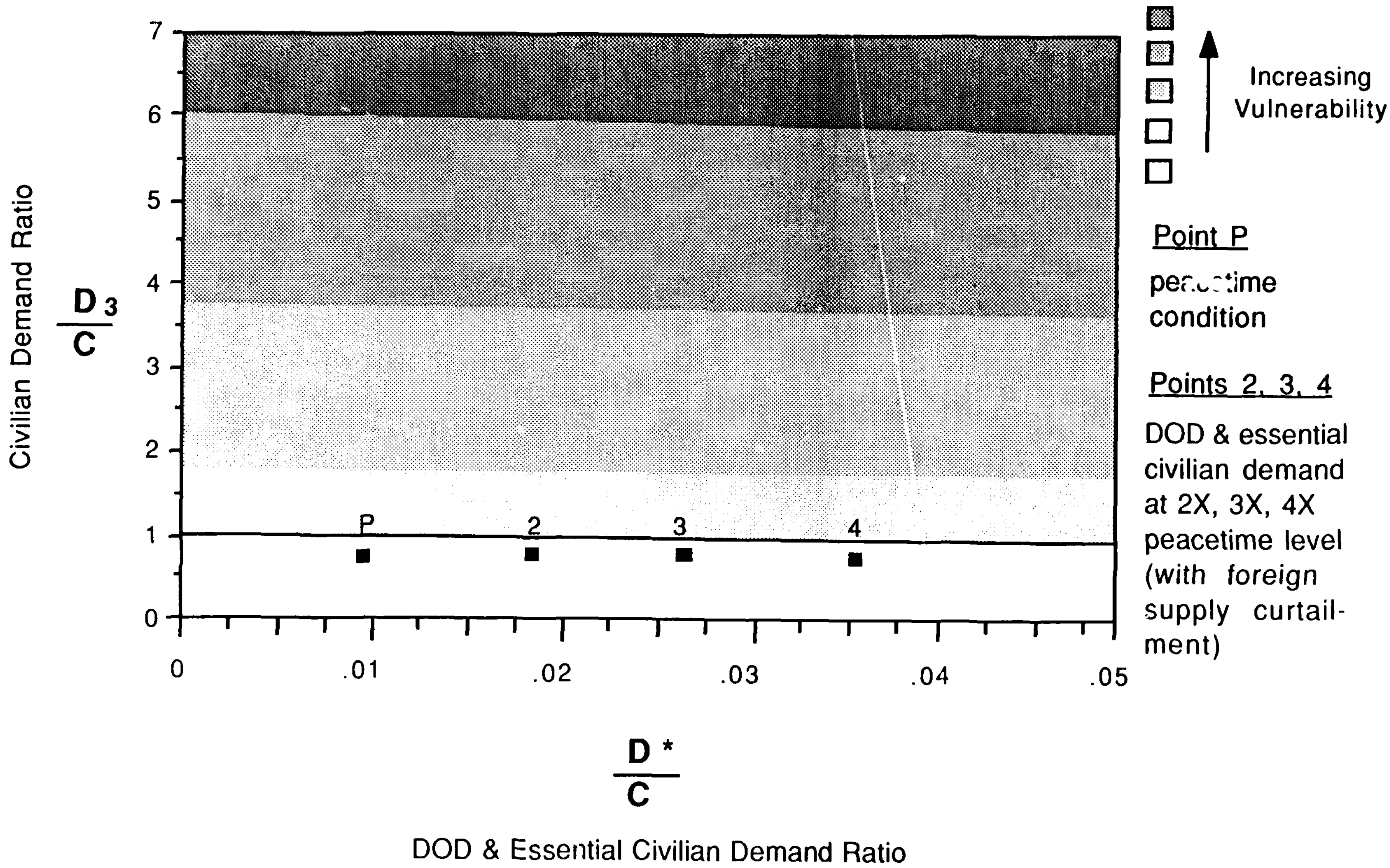


FIGURE E-9

VULNERABILITY ASSESSMENT

Process/Form Comparison for Chromium

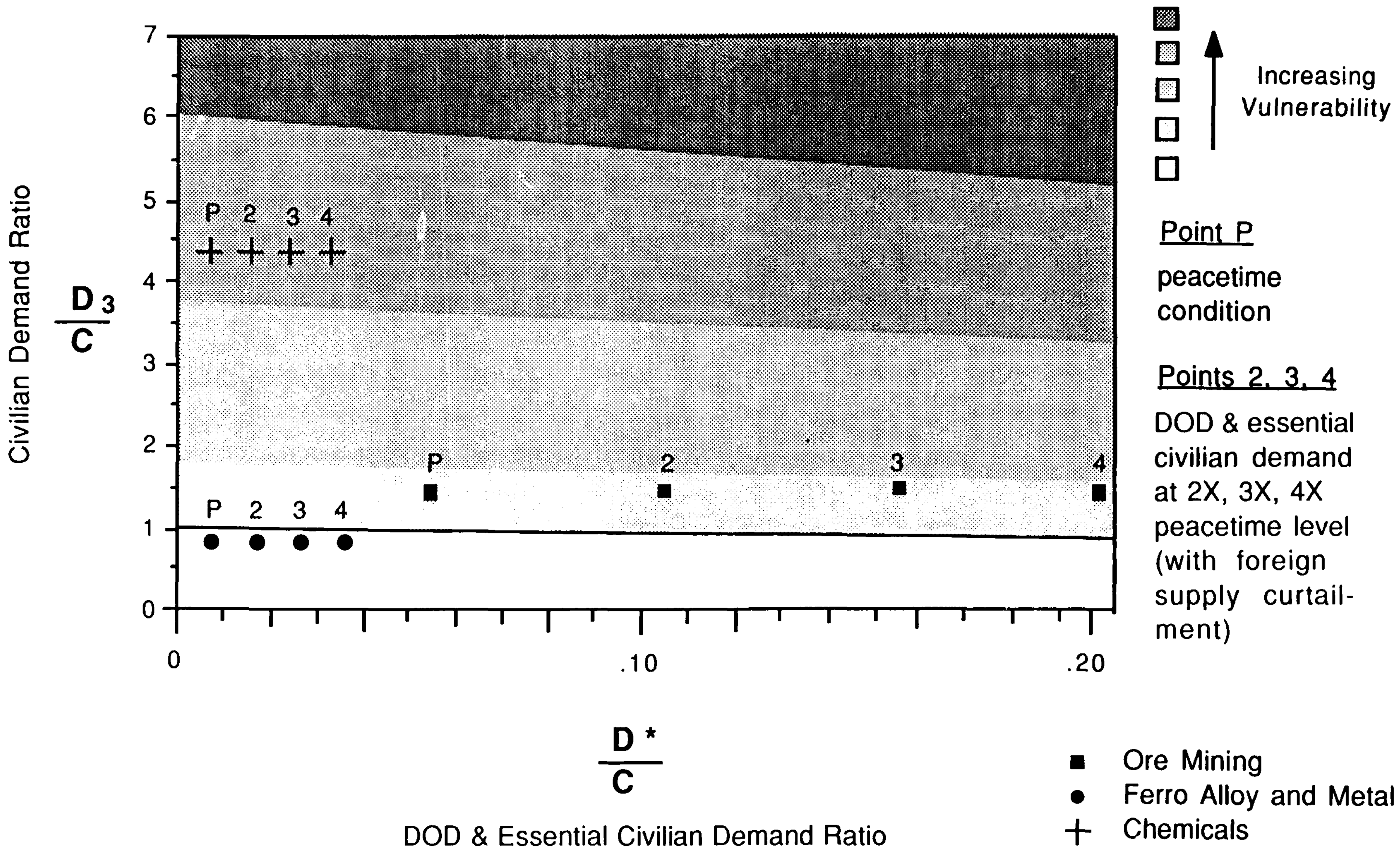


TABLE E-5
CHROMIUM DOMESTIC CAPACITY ANALYSIS SUMMARY
RELATIVE VULNERABILITY INDEX

CHROMIUM — INCREASING VULNERABILITY →

PROCESS	PRODUCT FORM	NOT VULNERABLE	SLIGHTLY VULNERABLE	VULNERABLE	VERY VULNERABLE	EXTREMELY VULNERABLE
MINING	ORE				P, 2, 3, 4	
CHEMICAL	CHEMICALS	P, 2, 3, 4				
SMELTING/ ARC FURNACE ELECTROLYTIC	FERROALLOYS AND METALS		P, 2, 3, 4			

P - PEACETIME
2 - DEMAND (2X PEACETIME DEMAND)
3 - DEMAND (3X PEACETIME DEMAND)
4 - DEMAND (4X PEACETIME DEMAND)

(187,000 tons). Chromium chemicals are the only product form that appears to have no capacity vulnerability from this analysis. No historical trend data was obtained through open sources for the production capacity of these chromium process/product forms.

CHROMIUM CAPACITY ANALYSIS SUMMARY

Chromite ore is not mined domestically primarily due to the low grade of U.S. deposits (generally much less than 20% Cr_2O_3). Domestic convertible mining capacity (i.e., less than one year) has been estimated to be 5,000 annual tons of contained chromium to supply a total chromite ore demand of 22,000 tons in 1985 for primarily refractory end-use. Estimated DOD and essential civilian demand for chromite ore (40 tons) is much less than one-percent of total domestic demand.

Estimated existing and convertible capacity to produce chromium metal and ferroalloys of 187,000 annual tons and 195,000 tons of imports supply total demand of around 285,000 tons in 1985. An estimated 9,750 tons of metal and chromium ferroalloy demand was generated by the DOD and essential civilian sector (3.5% of total metal and ferroalloy demand). A small amount of chromium chemicals (5,000 tons) are imported against an overall domestic demand of 71,000 tons in 1985. Estimated annual capacity to produce these chemicals is 88,000 tons in 1985. The chromium product form flowsheet in Figure E-10 indicates a recurrent theme, namely a chromium ore mining capacity "pinchpoint." This process/product flowsheet ties the various elements of chromium product supply and demand together. Ferroalloys and metals production were also categorized as a vulnerable process/product combination.

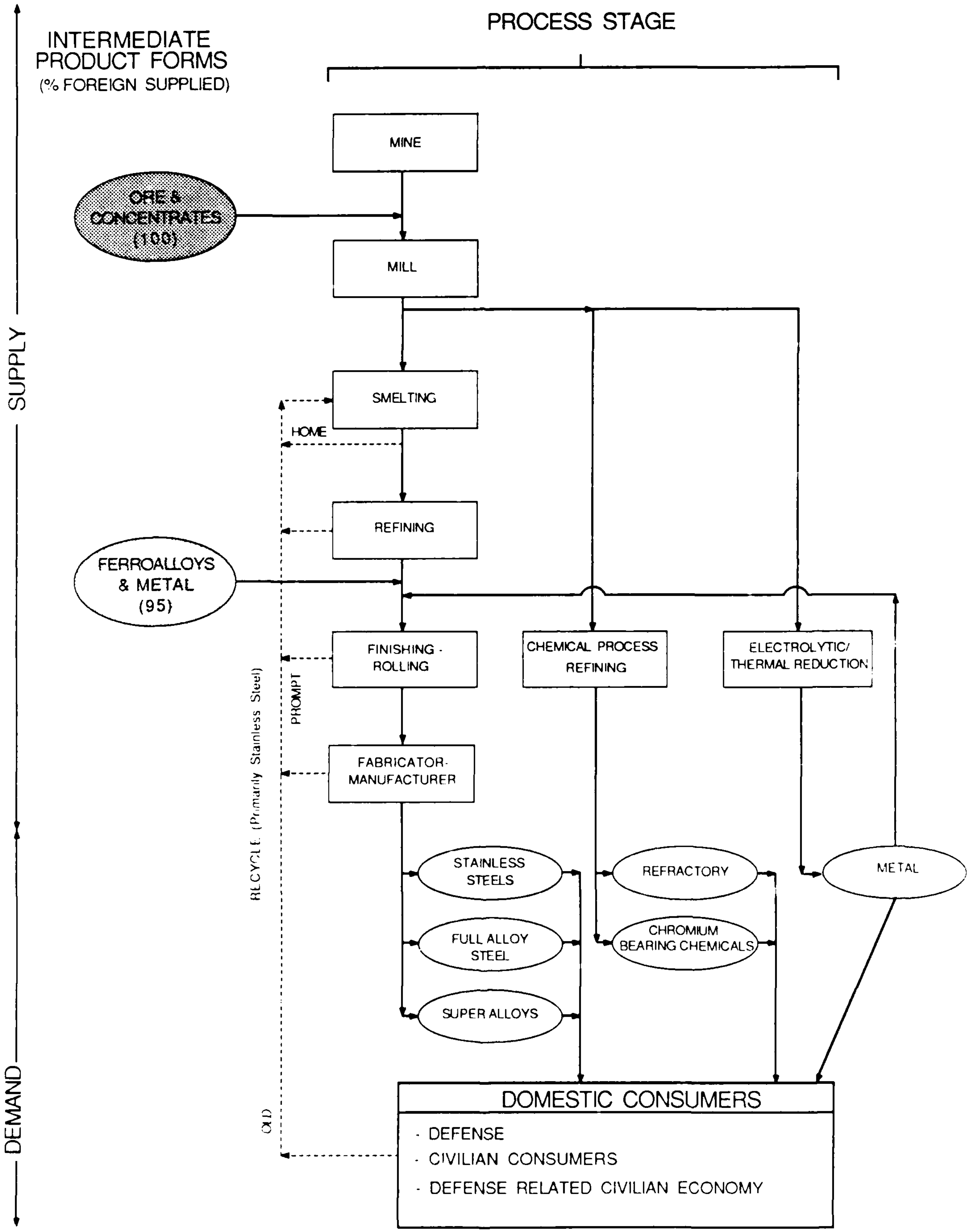
REFERENCES

1. Papp, J.E., "Chromium," Mineral Facts and Problems, U.S. Bureau of Mines, Washington, D.C., 1985, pp. 139-155.

2. National Materials Advisory Board. Contingency Plans for Chromium Utilization. Natl. Academy of Sciences, Washington, D.C., NMAB-335, 1978, 347 pp.

3. U.S. Department of Commerce, Critical Materials Requirements of the U.S. Steel Industry, March 1983, p. 62-63.

FIGURE E-10
CHROMIUM PRODUCT FORM FLOWSHEET



APPENDIX F

COBALT INDUSTRY STRUCTURE

Overview

Cobalt has developed from an obscure coloring additive, first used several thousand years ago, into a strategically important metal, the use of which is essential in the production of many defense-related items. Because of its diverse physical properties, it has many diverse end uses. In most of its applications, cobalt imparts essential qualities such as heat resistance, high strength, wear resistance, and superior magnetic properties. Major uses include jet engine parts, cutting tools, electrical devices, permanent magnets, catalysts, pigments and dryers for paints and allied products.[1]

Although the United States is the largest consumer of cobalt, typically accounting for about one-third of total world consumption, this country has produced no cobalt since 1971. Domestic cobalt resources are relatively large, but because of their low grades, production from these deposits is not economically feasible.

Cobalt mine production in the United States ceased at the end of 1971. All production since that time has been from relatively minor amounts of secondary material derived from recycled alloy.[1]

Known U.S. cobalt-bearing deposits which represent the current U.S. cobalt reserve base contain some 310,000 metric tons of cobalt in slightly over 1 billion metric tons of demonstrated mineralized material. Approximately 37 percent of the cobalt contained in the reserve base is considered recoverable using existing technology.[2]

Geographic Distribution

The top five producers of cobalt in terms of world mine output (estimated recovered content of ore) in 1983 were Zaire (47%), Zambia (13%), U.S.S.R. (10%), Australia (8%), and Cuba (7%).

The primary producer of cobalt in the world, Zaire, contributed 30% of total world metal production in 1983. One company, the Government-owned Generale des Carriers et des Mines (Gecamines), mines most of the copper and cobalt in Zaire.

Belgium processes about one-third of the cobalt exported by Zaire and, in turn, exports about one-half of its production to the United States. In addition, about 1 million pounds per year of cobalt is treated in the United States, principally from imported matte produced in Botswana and Australia.[1]

Sulfide and oxide concentrates produced from the ores mined by Gecamines are processed to cobalt metal at the Shitura and Luilu electrolytic plants in Likasi and Kolwezi, respectively. The Shituru and Luilu plants both produce cobalt cathodes. The Shituru plant also produces granules.

Cobalt is also a by-product of Zambia's copper industry. The two major state-owned mining companies in Zambia, Nchanga Consolidated Copper Mines

Ltd. and Roan Consolidates Mines Ltd., have merged to become Zambia Consolidated Copper Mines Ltd.

In Canada, Inco Ltd. produces commercial-grade cobalt oxide in Manitoba. The new Inco electrolytic cobalt refinery in Port Colborne, Ontario, became operational in 1983. The facility has a production capacity of 2 million pounds per year. Refined cobalt oxides are processed at Inco's refinery at Clydach, Wales (using oxide shipped from Canada). Falconbridge Nickel Mines Ltd. exports cobalt-bearing matte from its mines and smelters in Canada to its refining operation in Kristiansand, Norway. Cobalt is also recovered as a by-product of nickel and copper concentrates by Sherritt Gordon Mines Ltd. at its refinery in Fort Saskatchewan, Alberta.

Cobalt is produced in Australia by Freeport Queensland Nickel Inc. (a subsidiary of Freeport Minerals Inc. of New York) and Metals Exploration Queensland Pty. in Greenvale, Australia.

Cuba produces a nickel-cobalt sulfide concentrate and a nickel-cobalt oxide that are sent to the U.S.S.R. and Czechoslovakia, respectively, for refining.[1]

Grades and Specifications

About 70% of the cobalt consumed in the United States is in some form of the metal, such as briquettes, granules, broken cathodes, rondelles, fines, or powder. More than 20% of the cobalt produced in the world is consumed in various chemical compounds other than oxide, and more than 5% is used as an oxide, principally gray cobaltous oxide (CoO) and black cobaltic oxide (Co_3O_4). Cobalt salt producers generally market about six cobalt compounds, including acetate, carbonate, chloride, nitrate, and sulfate. The National Defense Stockpile purchase specifications designate three grades of cobalt, electrolytic broken cathodes (grades A and B) and granules. The material designated grade A must contain a minimum of 99.9% cobalt; grade B, 99.65%, and granules, 99.5%.[1]

COBALT INDUSTRIAL APPLICATIONS

Overview

Cobalt is sold in a wide variety of products and forms, the most common being electrolytic cathode. High-purity cathodes have been the products most commonly used in the superalloy industry and other industries with stringent purity specifications. Cobalt is also commonly produced as a hydrogen-reduced powder, with the powder sometimes briquetted or sintered before shipping. Cobalt is processed into a variety of chemicals for sale to the chemical industries, the most important of which is cobalt oxide. Specialty products include extra-fine powder, used in producing cemented carbides.

The data on U.S. consumption of cobalt by use show that superalloys, magnets, and chemical salts and driers provided the three most important uses for cobalt. Cutting and wear-resistant materials (cemented and sintered carbides), welding and hardfacing materials, tool steels, and catalysts required less cobalt.

The major use of superalloys is in gas turbines for either jet engines or industrial applications. Some alloys that are classified as superalloys are used in implanted medical prosthetic devices, such as artificial hip joints.

Concerning cobalt, superalloys can be classified as cobalt-base (40 percent or more cobalt), cobalt-bearing nickel-base (8 to 20 percent cobalt), and cobalt-free nickel-base. Cobalt is used in superalloys because it enhances high-temperature mechanical properties and processability. In addition, cobalt-base alloys can be air-melted, and those with carbon content are easily weldable.[3]

Permanent magnets made with cobalt are generally superior to other magnets because cobalt is the strongest magnetic element. Cobalt increases the saturization magnetization of iron and has the highest Curie temperature known. The most commonly used magnetic materials are aluminum-nickel-cobalt alloys, collectively known as Alnicos. The most important of these is Alnico V, containing 24 percent cobalt. Other magnetic materials containing cobalt include Remalloy, rare earth-cobalt (usually cobalt-samarium), chromium-iron-cobalt alloys (chromindur), and soft magnetic alloys such as Permendur and Vicalloy.[3]

Cobalt is used in cutting and wear-resistant materials as a binder for tungsten carbides and mixed carbides. Tungsten carbide powder, and lesser amounts of tantalum, titanium, and other carbide powders, are mixed with powders in the iron group (cobalt, iron, and nickel) and sintered to form cutting tools, drill bits, and the like.

Hardfacing materials are welded onto base materials to provide a layer resistant to abrasion and corrosion, particularly where lubrication is not possible. Engine valves provide a major use for hardfacing alloys. The most important cobalt-bearing alloys used in hardfacing have cobalt contents ranging from 45 to 65 percent.

Tool steels constitute a relatively minor use for cobalt in the United States. High-speed tool steels are the most important as far as cobalt is concerned. Cobalt is added to high-speed steels to increase attainable hardness and improve hot hardness and hardness retention.

Cobalt catalysts are used in the production of isooctyl alcohols (for manufacturing polyvinyl chloride) and unsaturated polyesters. Cobalt-molybdenum catalysts on an alumina carrier are used widely to desulfurize petroleum fractions. Molybdenum is the active catalyst in the reaction, and cobalt acts as a promoter.

Oxides, inorganic salts, and organic salts of cobalt are used widely. Organic cobalt salts, such as cobalt naphthenate and oleate, are used as driers in inks, varnishes, and oil-base paints because of this catalytic action. Cobalt is primarily a surface drier, so it is normally used with other driers, such as manganese, to promote fast, even drying of paint films.[3]

By far the largest use of cobalt at present is in superalloys. Current formulations contain cobalt and will continue to do so for the foreseeable future.

Substitution Technology

Current research indicates that significant amounts of cobalt in superalloys can be replaced by nonstrategic elements. However, implementation of these results requires costly and time-consuming alloy optimization and engine certification programs, which, unless coupled with engine performance advantages, will begin only when warranted by sufficient economic incentive or sufficiently urgent insecurity of supply.

Substitutes for cobalt as a catalyst or as a drier in paints are usually not effective. In drier applications, manganese and lead can act either as a complement or as a substitute. In catalytic applications, molybdenum and aluminum are complements, and nickel and tungsten together are substitutes for cobalt. However, use of nickel in petroleum catalysts yields lower octane gasoline and required higher processing pressures to be effective.

No satisfactory substitutes have been developed for use of cobalt as the binder in cemented carbides. However, research is being directed toward developing alloys with a base of nickel, vanadium, chromium, or tungsten that have binding properties equal or superior to those of alloys containing cobalt.

COBALT SUPPLY/DEMAND RELATIONSHIPS

Breakdown of U.S. Cobalt Consumption by Product Form

U.S. cobalt consumption is segmented into cobalt product forms in Figure F-1. In 1985, the primary usage of cobalt was in the form of 6,119 tons of cobalt metal (74.7% of total consumption) for manufacture of superalloys, wear-resistant alloys, tool steels, and other alloys. Cobalt oxides comprised 1,312 tons of consumption (16% of total consumption) primarily used as a pigment and glass coating base. Cobalt in miscellaneous chemical forms and end-uses makes up the difference in domestic demand.

Cobalt: Supply/Demand Relationship-1985

A world supply/U.S. domestic demand relationship for cobalt is shown in Figure F-2. World mine production of cobalt is estimated to be 29 million annual tons of which the U.S. has no contribution. Of a total U.S. cobalt demand in 1985 of 8,193 tons, all primary use was effectively supplied by the 8,854 tons of import. The domestic demand for cobalt is fairly lopsided with transportation (3,697 tons) and, paints (1,312 tons) economic sectors making up more than 61% of total cobalt demand. Other industrial sectors that use cobalt include: electrical, machinery, chemicals and others.

Cobalt Domestic Supply/Demand Relationship: 1975-1985

A historical perspective of the United States dependence on foreign cobalt metal/alloy capacity to supply domestic demand is shown in Figure F-3.

FIGURE F-1
Total U.S. Cobalt Consumption By Form
(Short Tons)

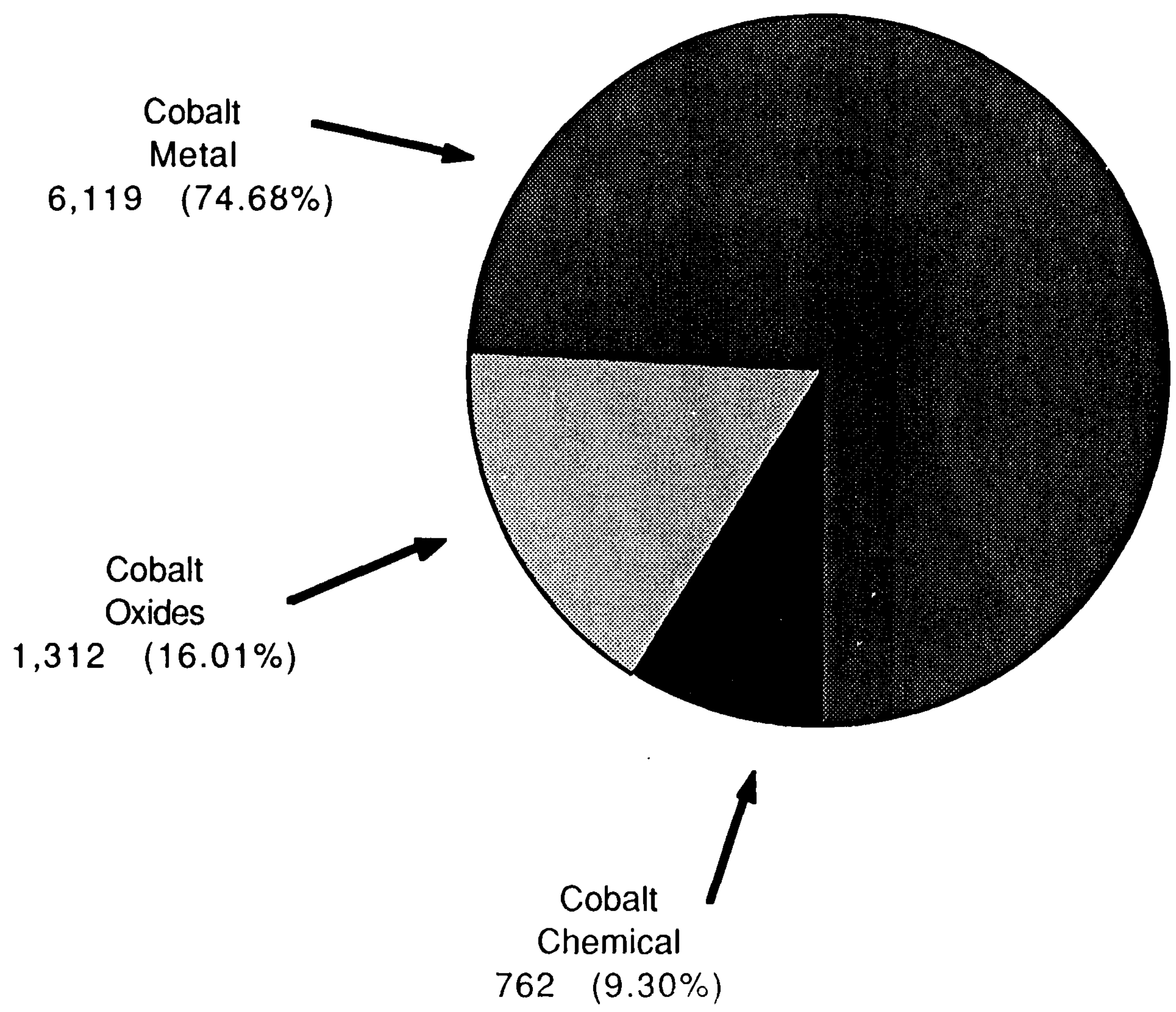
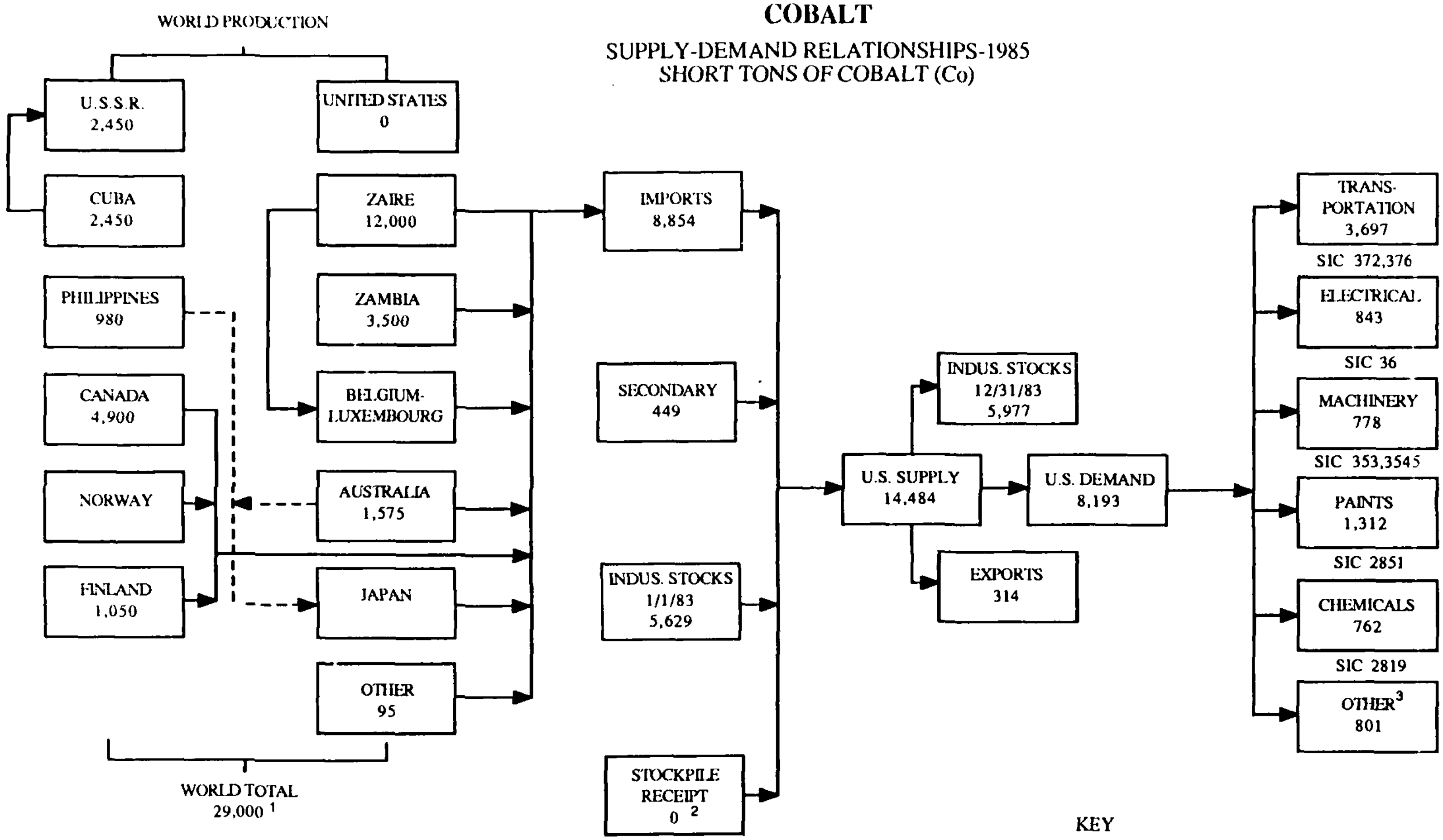


FIGURE F-2
COBALT
SUPPLY-DEMAND RELATIONSHIPS-1985
SHORT TONS OF COBALT (Co)

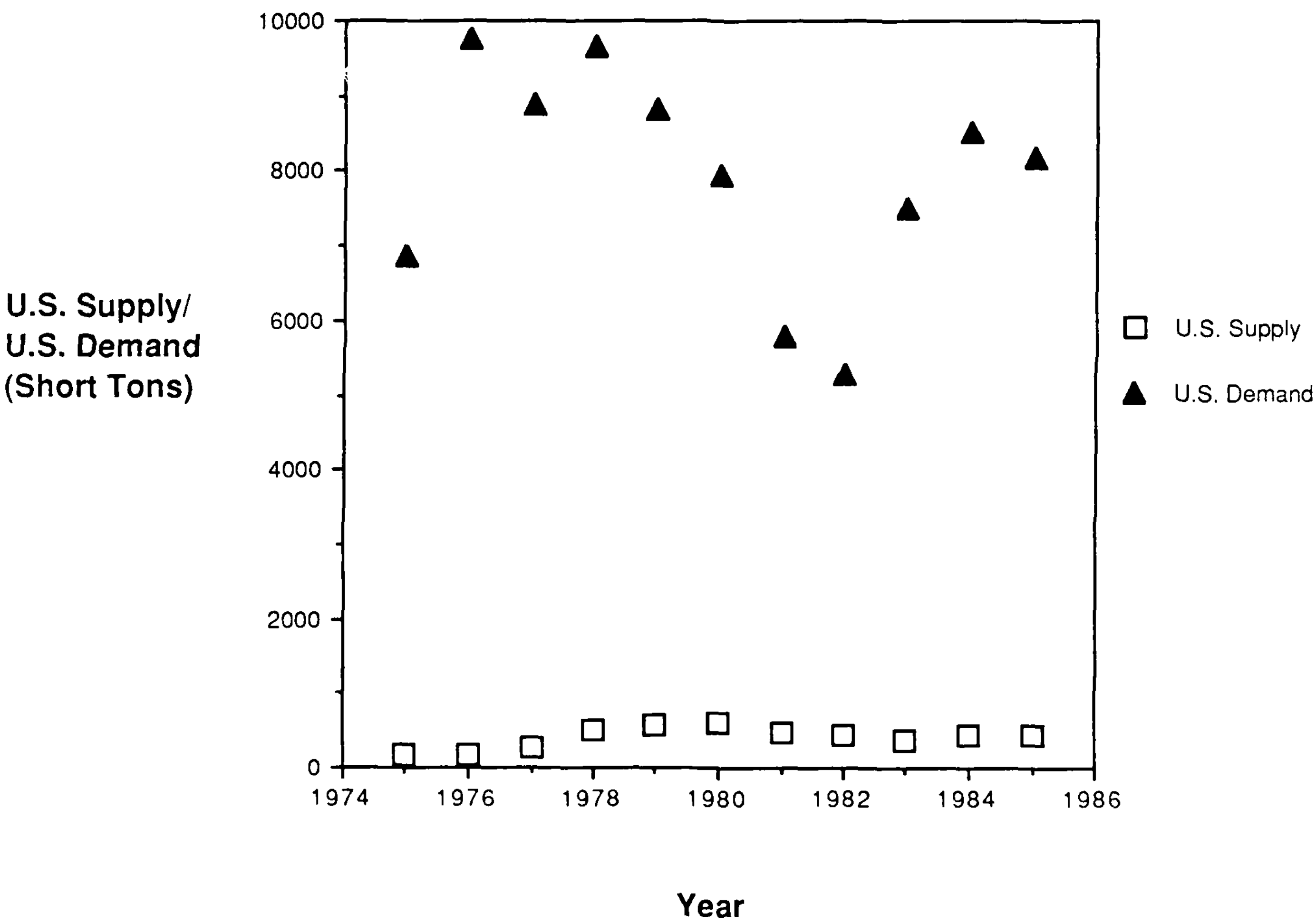


KEY

SIC: STANDARD INDUSTRIAL CLASSIFICATION
- - - ALLOY IMPORTS
—— COBALT IMPORTS
1 DATA DO NOT ADD TO TOTAL SHOWN BECAUSE OF INDEPENDENT ROUNDING.
2 DENOTES QUANTITY OF STOCKPILE COBALT PURCHASE IMPORTED.
3 INCLUDES CERAMICS AND GLASS.

Source: U.S. Bureau of Mines and Arthur D. Little, Inc. estimates based on internal and industry sources.

Figure F-3
Cobalt Metal/Alloys: Domestic Supply - Demand Relationship, 1975-1985



U.S. domestic secondary production of cobalt metal and superalloy supplies a small fraction of overall demand.

World Cobalt Producers-1983

Producers of cobalt ore and products worldwide are listed in Table F-1. The only domestic producer, AMAX Inc., began significant production at its refinery in Braithwaite, Louisiana, in 1975 and greatly improved operations in 1979. Rated capacity of the plant is 2 million pounds of cobalt per year. Nickel-cobalt and nickel-copper-cobalt matte is supplied to the plant from Botswana and Australia.

Recycle Flow for Cobalt

Recycling of cobalt scrap has increased significantly over the past few years rising from an estimated 400 tons in 1985 to 1300 tons in 1987, representing about 16% of estimated reported consumption for this year. Most secondary sources of cobalt are derived from:

- Superalloy scrap, or
- Cemented carbide scrap.

About 13 recyclers accounted for nearly all cobalt recycled in superalloy scrap. (BuMines, Mineralt Commodity Summaries, 1988).

Estimated DOD-Related and Civilian Demand

Critical to this analysis of cobalt capacity/demand balance is the segmentation of total U.S. domestic demand (D_T) into its three components: Civilian demand (D_3), essential civilian demand (D_2), and estimated DOD demand (D_1). Analysis by Arthur D. Little, Inc., for FEMA using the INFORUM database converted domestic cobalt demand in U.S. dollars to estimated tons of cobalt content for DOD and essential civilian end use. This analysis for cobalt (an example of the calculations are in Appendix A), further segmented domestic cobalt demand into end-use economic sectors--transportation, paints, electrical, chemical, machinery, and other.

Cobalt Form Consumed for Each Economic Sector

In order to analyze the capacity/demand balance for a particular material process/product form, the percentage of various product forms being supplied to particular end-use economic sectors must be estimated. In the case of cobalt, there were four process/product forms to be analyzed:

- Mining/Ore
- Chemical/Salts and Compounds
- Smelting or Reduction/Metal
- Chemical /Cobalt Oxides

Segmentation of total domestic demand in 1985 for each economic sector by cobalt product form is shown in Figure F-4. In addition, the segmentation of total domestic demand into estimated DOD & essential civilian demand

TABLE F-1

WORLD COBALT PRODUCERS

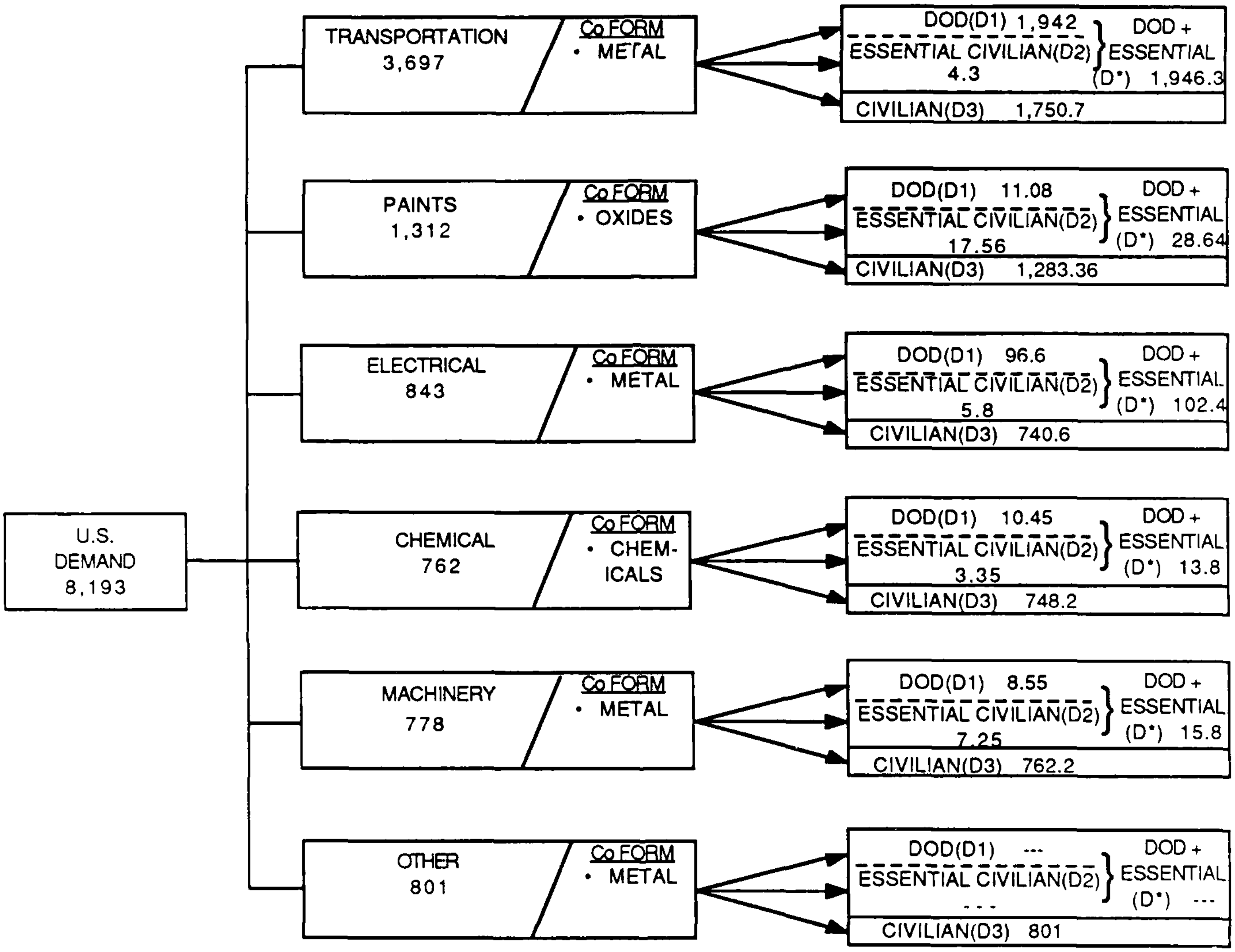
Country	Company
North America:	
Canada	Sherritt Gordon Mines Ltd.
	Inco Ltd.
	Falconbridge Ltd.
Cuba	Cubaniquel (State owned)
United States	AMAX Nickel Inc.
Europe:	
Belgium	Metallurgie Hoboken Overspelt S.A.
Finland	Outokumpu Oy (Government-owned)
France	Pechiney Ugine Kuhlmann
	Societe Le Nickel
Germany, Federal Republic of	Duisburger Kupferhutte
	Gesellschaft fur Electrometallurgie Gmbh
	Herman C. Starck
Norway	Falconbridge Nikkelverk AS
United Kingdom (Wales)	International Nickel Ltd.
U.S.S.R.	State plants located in Balkhash, Touva (Khozuakay), Norisk, and Verkni-Oufalel
Africa	
Botswana	Botawana RST Ltd.
South Africa, Republic of	Rustenberg Platinum Mines Ltd.
	Impala Platinum Ltd.
Zaire	La Generale des Carriers et des Mines
Zambia	Zambia Consolidated Copper Mines Ltd.
Asia: Japan	Nippon Mining Co. Ltd.
	Sumitomo Metal Mining Co. Ltd.
Oceania:	
Australia	Freeport Queensland Nickel Inc.
	Metals Exploration Queensland Ply.
	Western Mining Co.
New Caledonia	Societe Le Nickel
Philippines	Marinduque Mining and Industrial Corp.

Source: U. S. Bureau of Mines

FIGURE F-4

U.S. COBALT DEMAND BREAKDOWN (1985)

(SHORT TONS)



Source: U. S. Bureau of Mines and Arthur D. Little, Inc.
Estimates based on Inforum Data

(D^*) and civilian demand (D_3) allows the computation of cobalt domestic demand on a process/product form basis also shown in Figure F-4.

COBALT CAPACITY ANALYSIS

Cobalt vulnerability analysis data segmentation of total U.S. domestic cobalt demand into estimated DOD and essential civilian demand categories in Appendix A, breakdown of U.S. cobalt demand by process/product form in Figure F-4 along with supply and capacity estimates are compiled and consolidated in Table F-2. This data is used to generate U.S. domestic demand/domestic capacity ratios in Table F-3 to perform the capacity vulnerability analyses for cobalt.

Cobalt Vulnerability Analysis

Capacity vulnerability analysis charts for the production of cobalt ore, cobalt metal, cobalt oxides, and cobalt salts or compounds are shown in Figure F-5 through Figure F-8, respectively. A comparison of all cobalt forms on one vulnerability chart is shown in Figure F-9. Cobalt production capacity vulnerability has been segmented into five categories--not vulnerable, slightly vulnerable, vulnerable, very vulnerable, and extremely vulnerable as indicated in Table F-4. Cobalt ore mining capacity falls into one of three categories: "vulnerable" for peacetime demand, "very vulnerable" for two-times (2x) peacetime demand, and "extremely vulnerable" for three- and four-times (3x, 4x) peacetime demand. Cobaltous oxides fall into the "very vulnerable" category using this capacity vulnerability analysis for all demand levels. As with ore mining capacity, production and refinement of cobalt metal is largely done off-shore leading to capacity vulnerability and a metal category of "extremely vulnerable."

COBALT CAPACITY ANALYSIS SUMMARY

Although the U.S. has no domestic mining capacity for cobalt, total domestic consumption is estimated to be 8,193 annual tons, or around 20% of the estimated 39,867 annual tons of foreign supply. Compounding the estimated capacity vulnerability is the relatively high percentage of total demand that estimated DOD and essential civilian represents--25.7%. In the event of a national emergency, convertible cobalt mining capacity would be pressed to insure supply to this segment of demand in a timely manner.

Looking at Table F-2, estimated existing and convertible capacity for ore mining could supply 42.7% of total demand in 1985. Whereas for cobalt oxides, estimated capacity (320 tons cobalt content) would meet only 24% of total domestic demand in 1985, and estimated metal production capacity (147 tons cobalt) would meet only about 2.4% of total U.S. demand in 1985. These capacity "pinchpoints" are more completely and graphically presented in Figure F-10. In the case of cobalt, three out of the four major product forms (i.e., ore, metals, and oxides) all show some degree of capacity vulnerability by this analysis.

REFERENCES

1. Fisk, W.S., "Cobalt", Mineral Facts and Problems, U.S. Bureau of Mines, Washington, D.C., 1985, pp. 171-183.

TABLE F-2

COBALT VULNERABILITY INDEX DATA - 1985

Short Tons per Year
(Cobalt Content)

COBALT		TOTAL Co DEMAND (D_T)	DOD & ESSENTIAL CIVILIAN DEMAND (D^*)	EXISTING & CONVERTIBLE DOMESTIC CAPACITY (C)	DOMESTIC SUPPLY (S)	NON-DOMESTIC SUPPLY	CIVILIAN DEMAND (D_3)
PRODUCT FORM	PROCESS STAGE						
ORE	MINING	8,193*	2,107**	3,500 e	0.0	39,867	6,086
OXIDES	MISCELL-ANEOUS	1,312	28.64	320 e	209 e	N.A.	1,283.36
SALTS, COMPOUNDS	CHEMICAL	762	13.8	2,499 e	1749 e	N.A.	748.2
METAL	ELECTROLYTIC REDUCTION	6,119	2,064.5	147 e	103 e	24,227 e	4,054.2

Source: U.S. Bureau of Mines and
National Materials Advisory Board

e *Arthur D. Little estimates based on internal and industry sources.*

N.A. Not Available

** Estimate assuming total of all other forms (i.e. oxides, salts, compounds, and metal)

TABLE F-3

COBALT DOMESTIC DEMAND/ DOMESTIC CAPACITY RATIOS

	PEACE TIME		INCREASED DEMAND		
			2X	3X	4X
	$\frac{D_3}{C}$	$\frac{D^*}{C}$	$\frac{2D^*}{C}$	$\frac{3D^*}{C}$	$\frac{4D^*}{C}$
Ore Mining	1.74	0.60	1.2	1.8	2.4
Oxides	4.01	0.089	0.179	0.267	0.356
Chemical (salts,compounds)	0.299	0.005	0.010	0.015	0.020
Metal	27.57	14.04	28.08	42.12	56.16

FIGURE F-5

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Cobalt Ore Mining

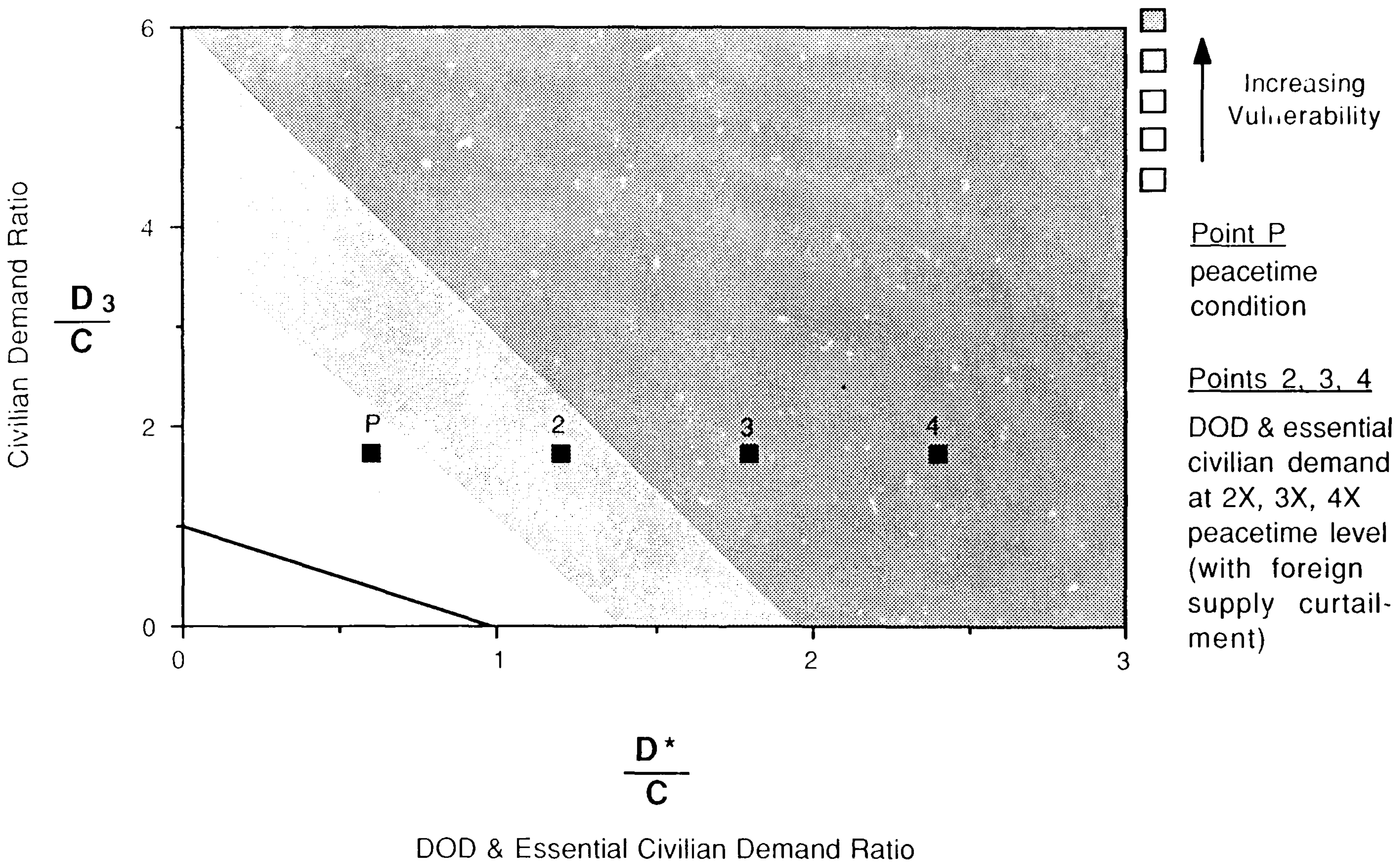


FIGURE F-6
VULNERABILITY ASSESSMENT
Demand/Capacity Balance: Cobalt Metal

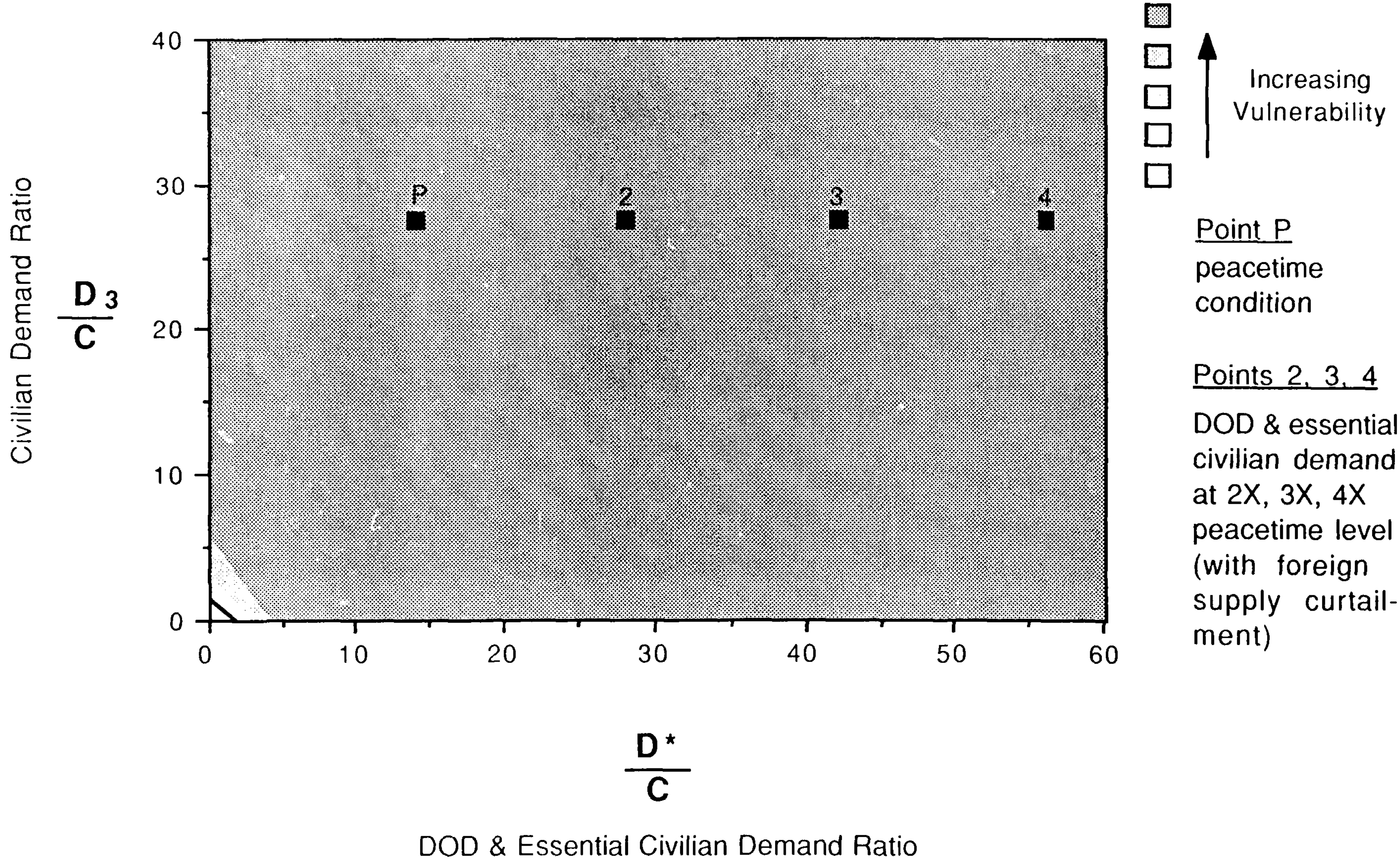
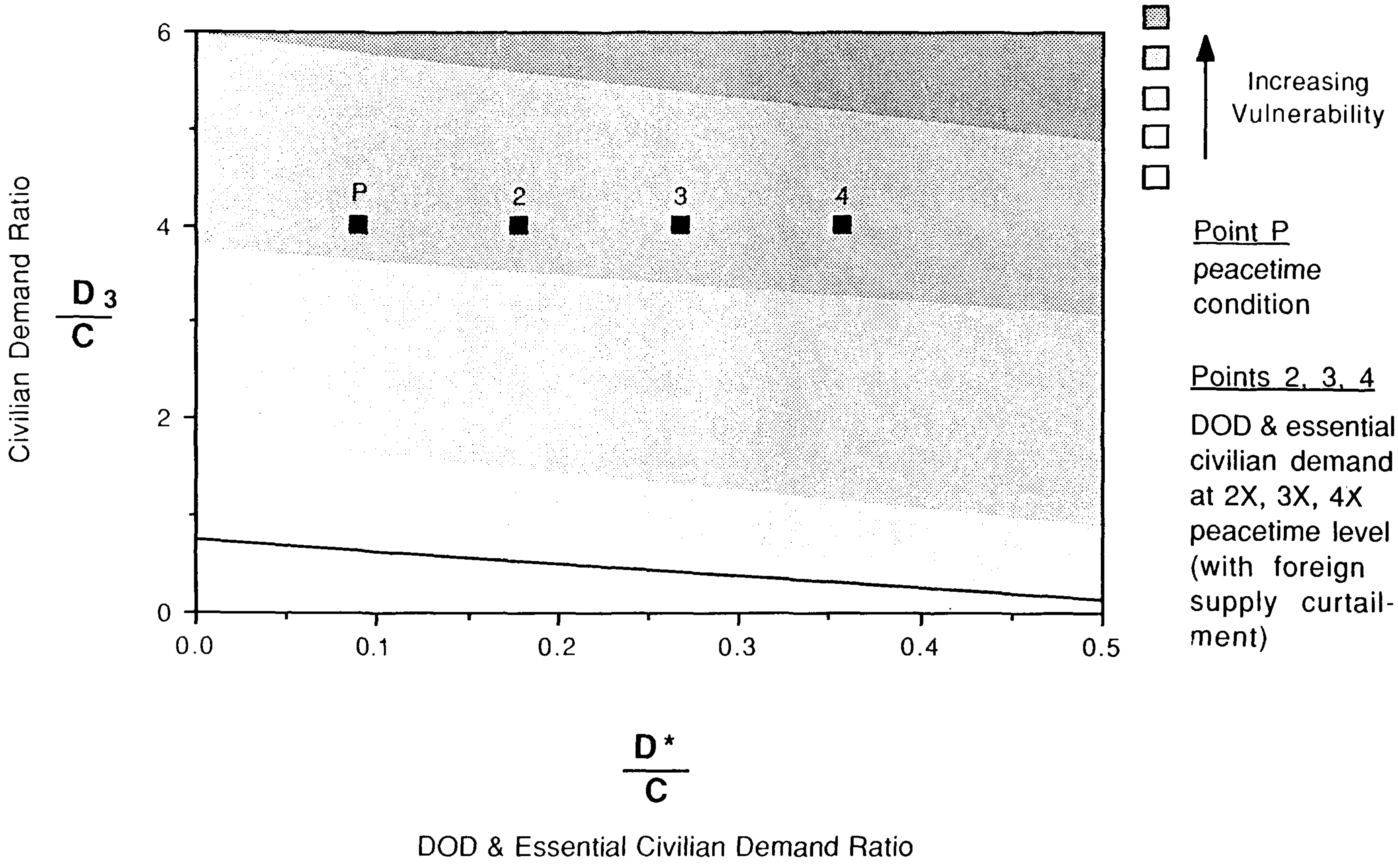


FIGURE F-7

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Cobalt Oxides



Arthur D. Little, Inc.

FIGURE F-8

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Cobalt Chemicals

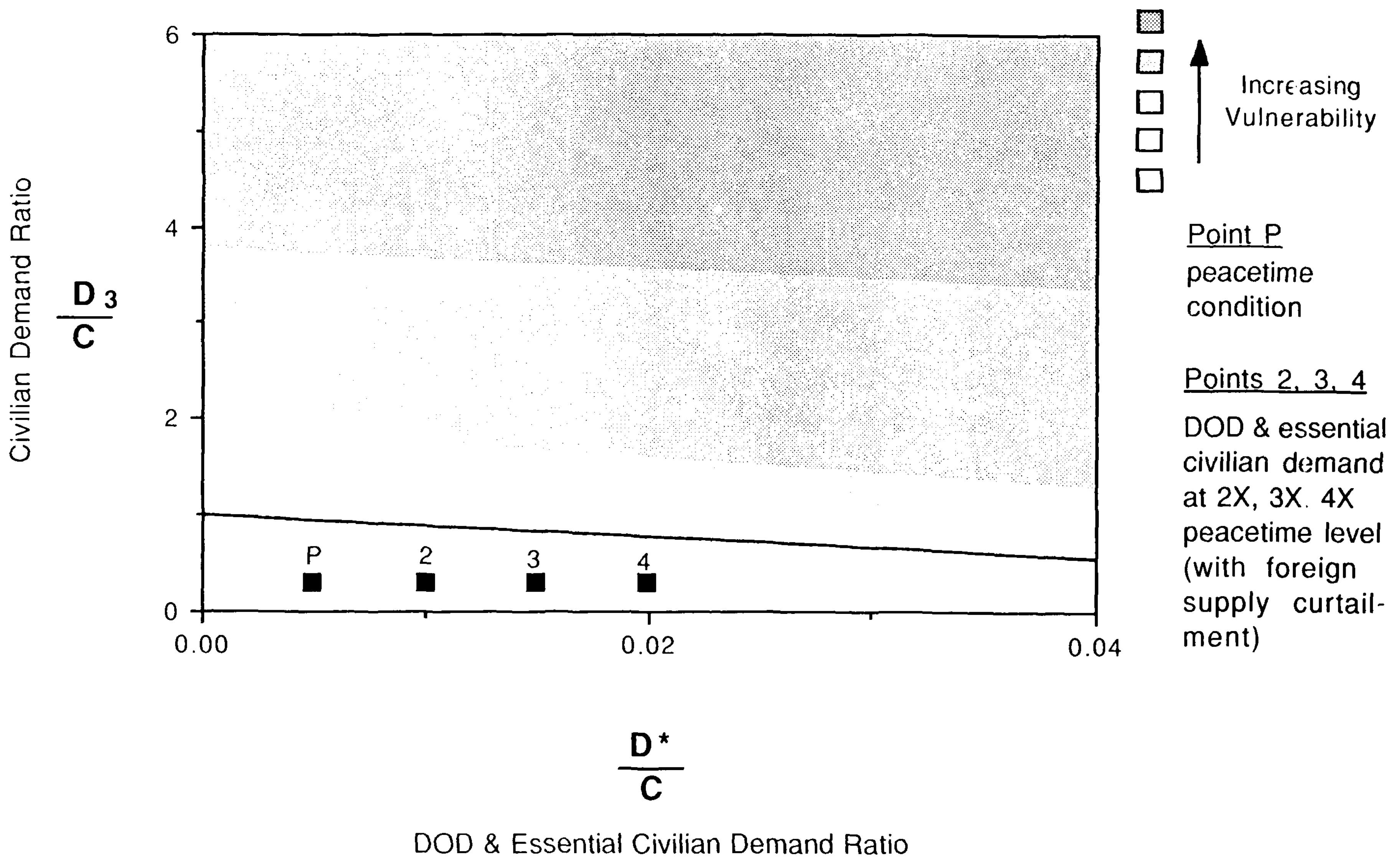


FIGURE F-9

VULNERABILITY ASSESSMENT

Process Form Comparison for Cobalt

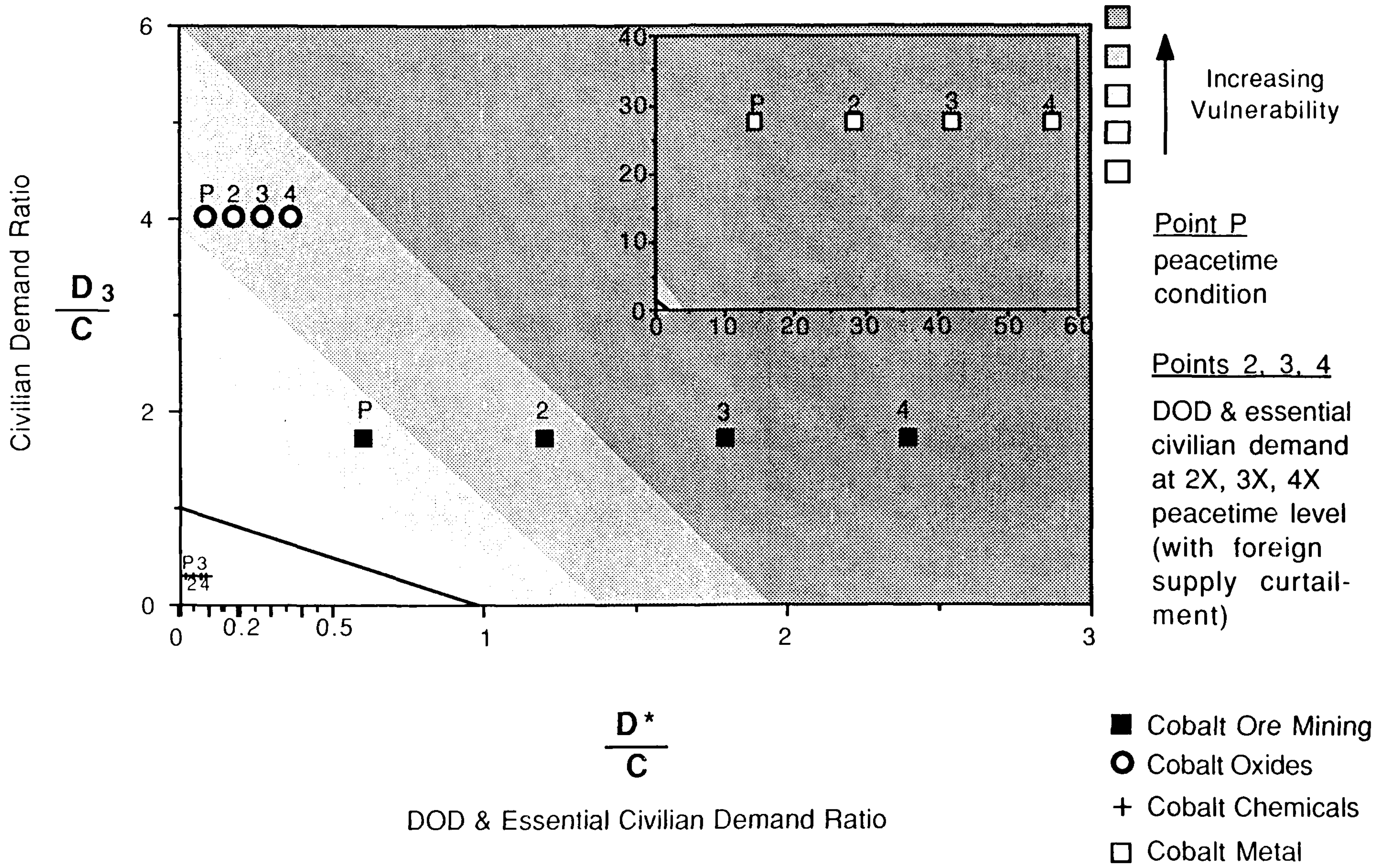


TABLE F-4
COBALT DOMESTIC CAPACITY ANALYSIS SUMMARY
RELATIVE VULNERABILITY INDEX

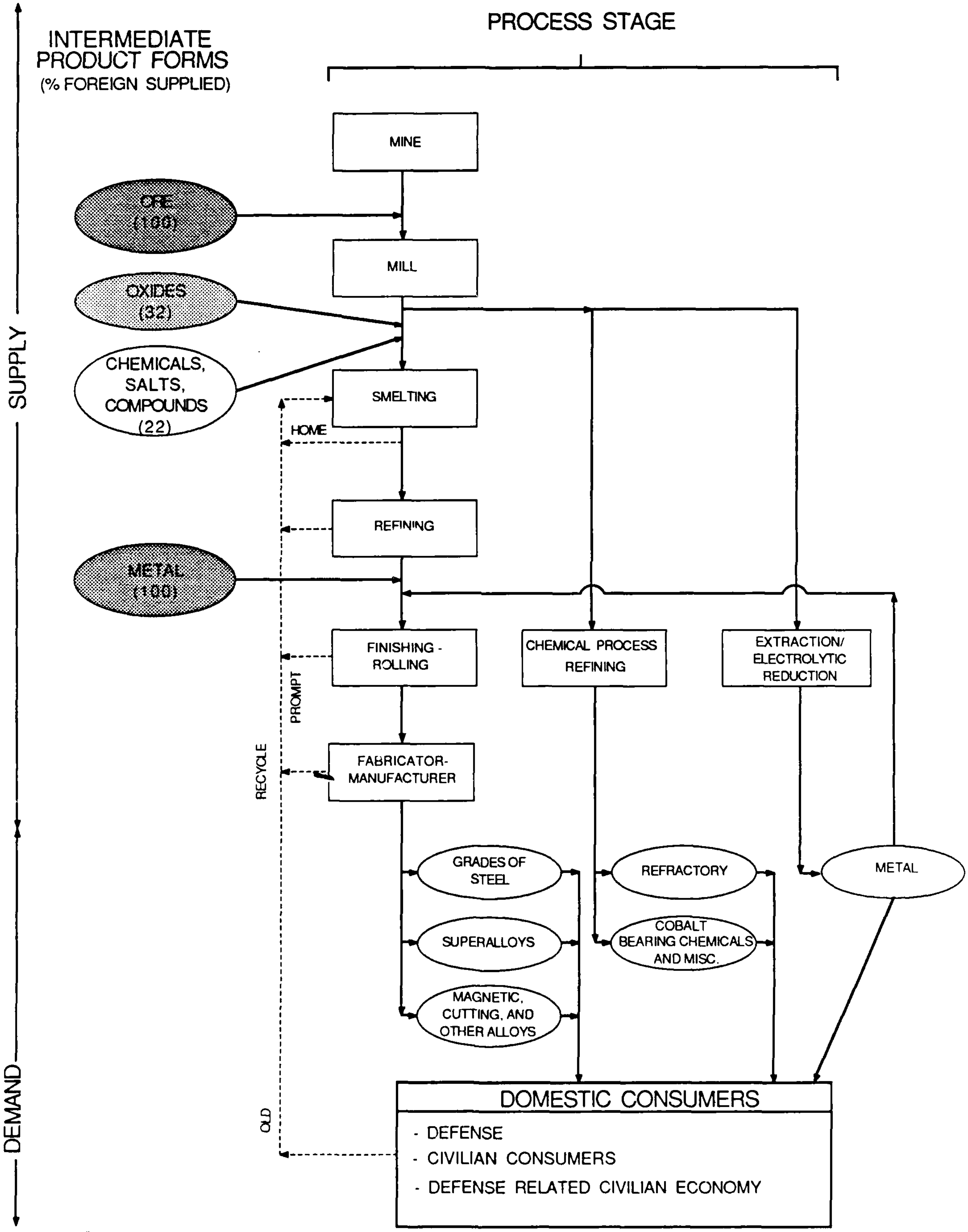
COBALT

INCREASING VULNERABILITY ⟶

PROCESS	PRODUCT FORM	NOT VULNERABLE	SLIGHTLY VULNERABLE	VULNERABLE	VERY VULNERABLE	EXTREMELY VULNERABLE
MINING	ORE			P	2	3, 4
MISCELL-ANEOUS	OXIDES				P, 2, 3, 4	
CHEMICAL	SALTS, COMPOUNDS	P, 2, 3, 4				
ELECTROLYTIC REDUCTION	METAL					P, 2, 3, 4

P - PEACETIME
2 - SURGE D DEMAND (2X PEACETIME DEMAND)
3 - SURGE D DEMAND (3X PEACETIME DEMAND)
4 - SURGE D DEMAND (4X PEACETIME DEMAND)

FIGURE F-10
COBALT PRODUCT FORM FLOWSHEET



2. Peterson, G.R., et al., "Cobalt Availability - Domestic, A Minerals Availability System Appraisal," U.S. Bureau of Mines, Information Circular 8848, Washington, D.C., 1981.

3. National Materials Advisory Board, "Cobalt Conservation Through Technological Alternatives," National Academy Press, Washington, D.C., 1983, p. 23-24.

APPENDIX G

TITANIUM INDUSTRY STRUCTURE

Overview

Titanium metal is one of the strategic and critical materials used primarily in the aircraft and aerospace industries, petrochemical processing industry, powerplants, marine applications, and steelmaking. Titanium metal accounts for only 4% of the total of 523,000 tons of titanium consumed domestically in 1983. The majority of titanium is consumed in the form of titanium dioxide (TiO_2), a pigment primarily used in surface coatings such as in paints, varnishes, lacquers, and paper products.

The sources of titanium include rutile and ilmenite. Rutile is 93% to 96% titanium dioxide. Ilmenite may contain 44% to 70% titanium dioxide. Ilmenite ore is refined to supply approximately 60% of the titanium metal and more than 85% of the TiO_2 pigment and nonmetal demand.

In 1983, the United States' reliance on imports was 58% of rutile and 81% of ilmenite ore. Much of this import supply came from Australia and Canada.

In Appendix G, an analysis of U.S. domestic capacity for the production of titanium product forms consumed will be compared against U.S. segmented demand to evaluate capacity vulnerability.

Geographic Distribution

Titanium, the ninth most abundant element, occurs in nature as a chemical compound containing oxygen and iron. Titanium is a high-value commodity which only gained commercial importance as a metal since 1948.

Other sources of titanium include leucoxene, synthetic rutile, and titanium slag all refined from ilmenite. Leucoxene concentrates may contain up to 90% titanium dioxide. Potential sources of titanium include deposits of anatase in Brazil and perovskite, a calcium titanate, in Colorado.

Principal world producers of ilmenite and titanium slag made from ilmenite are Australia, Canada, Norway, the Republic of South Africa, the United States and the U.S.S.R. Main producers of rutile are Australia, Sierra Leone, and the Republic of South Africa. Titanium metal is produced mainly by the U.S.S.R., United States, Japan, the United Kingdom, and China. Major producers of titanium dioxide pigment are the United States, the Federal Republic of Germany, the United Kingdom, Japan and France.

The United States mines about one-third of its titanium raw material requirements. U.S. producers of ilmenite ore are Associated Minerals (USA) LTD. INC., (AMU) at Green Cove Springs, Florida, and E.I. DuPont De Nemours & Co., Inc. at Starke and Highland, Florida. AMU is a subsidiary of Renison Goldfields Consolidated Ltd. of Australia. AMU is the only U.S. producer of natural rutile concentrate. Kerr-McGee Chemical Corp. was the sole domestic producer of synthetic rutile in Mobile, Alabama. The balance is primarily imported from Canada in the form of titanium slag and from

Australia in the form of rutile, synthetic rutile and ilmenite. Although the U.S. has large reserves of ilmenite ore, virtually all the U.S. sponge metal production has been derived from imported rutile or synthetic rutile. This fact is due to the preference for the higher purity (high TiO_2 content) natural or synthetic rutile feed material for the $TiCl_4$ based process both for titanium sponge and pigment production.[1]

Grades and Specifications

Specifications for rutile purity for the national stockpile shown in Table G-1 require a minimum of 95% purity with maximum impurity levels for a host of compounds and elements. Commercially, there are no rigid raw material specifications for making $TiCl_4$ to produce metal or pigment. Neither are there specifications for ilmenite ore or titanium slag used in the sulfate pigment process.

Final pigment properties are adversely affected by impurities such as chromium, vanadium, columbium, manganese, and phosphorus. This effects the degrees of freedom regarding feed concentrates. Raw materials to $TiCl_4$ production must also be low in calcium and magnesium, which create problems for the chlorination process.

The sulfate process for producing titanium dioxide pigment utilizes ilmenite, containing 45% to 60% TiO_2, or titanium slag, containing 70% to 75% TiO_2 also using ilmenite as a feedstock. Generally, the chloride-process based pigment and titanium metal production plants require higher purity (around 85% TiO_2) feed material such as rutile, synthetic rutile, or titanium slag. Rutile is used exclusively in the market economy countries for the production of metal.[1]

TITANIUM INDUSTRIAL APPLICATIONS

Overview

Titanium alloys are widely used in high performance military and commercial aircraft, primarily for their high strength-to-weight ratio, corrosion and elevated temeprature resistance for airframe and engine components. The major nonaerospace use of titanium metal is in powerplant surface condensers that use salt water. Other industrial applications using titaniums corrosion characteristics include chemical processing, oil refining and water desalination equipment. U.S. titanium metal consumption can be broken down into roughly 60% aerospace applications, about 20% other industrial uses and 20% additions to steel and other alloys.

Rutile concentrates are used directly in welding-rod coatings. Titanium carbides, an alternative to tungsten carbide, are used extensively in machine cutting tools in a matrix of molybdenum, nickel, or cobalt. Cutting tool coatings are available as titanium carbides, nitrides, or borides. Finally, organotitanium compounds are used as catalysts for various polymerization processes.[1]

Approximately 96% of titanium minerals are used to produce white titanium dioxide pigment. Because of its whiteness, high refractive index, and resulting light-scattering ability, titanium dioxides two allotropic forms,

TABLE G-1

National Stockpile Purchase Specification: Titanium Sponge or Granules, Summary of Chemical and Physical Requirements

	Type A	Type B	Type C	Type D
Chemical Requirements,[1] Percent				
Nitrogen	0.010	0.015	0.015	0.008
Carbon	.020	.025	.020	.020
Sodium	—	—	.19	.01
Magnesium	.08	.50	—	.08
Lithium	—	—	—	.09
Aluminum	—	.07	—	—
Chlorine	.10	.20	.20	.10
Iron	.08	.10	.04	.04
Silicon	.04	.04	.04	.04
Hydrogen	.005	.03	.05	.02
Oxygen	.10	.10	.10	.07
Water	.02	.02	.02	.02
Other elements, total	.05	.05	.05	.05
Titanium	99.6	99.1	99.3	99.6
Physical Requirements				
Brinell hardness number, maximum	100	120	120	100
Particle size distribution, %				
Minus 3/4 inch	100	100	100	100
Minus 1/2 inch	95	95	95	95
Plus 100 mesh	95	95	95	95

Type A - Magnesium reduced and finished by vacuum distillation
Type B - Magnesium reduced and finished by acid leaching or inert gas sweep distillation.
Type C - Sodium reduced and finished by acid leaching
Type D - Electrolytic

[1] All amounts are maximums except for titanium, which is a minimum

Source: U.S. Department of Commerce P-97-R7, June 2, 1982

rutile and anatase, are the predominant white pigment for paints, plastics, rubber, and other materials.[1]

Substitution Technology

Selection of titanium alloys over other materials in aerospace applications is primarily made on an economic basis. Aluminum alloys, high strength, low alloy steels or composite materials may be substituted for titanium in many structural applications. The problem is that a redesign and sometimes lower performance chracteristics are the result. Nickel steels in particular are competitive with titanium. Where corrosion is the critical factor stainless steels such as hastelloy, 90 copper-10 nickel, and composites may be substitutional. Tungsten carbide is generally substitutional for titanium carbide in cutting tool applications.

Rutile used in welding-rod coatings to stabilize the arc and prevent oxidation can be substituted to some extent using ilmenite, titanium slag and synthetic titanium dioxide. Also, sodium and potassium silicates can be substituted in some cases for arc stability. Limestone and fluorospar can be substituted for rutile in some protective fluxes.[1]

Certain heat treatment and leaching combinations to remove iron and other impurities from ilmenite ($FeTiO_3$) allow substitution for rutile as a feed material for commercial titanium tetrachloride ($TiCl_4$) plants. These materials are classified as synthetic rutile with a TiO_2 content from 88% to 95%.

TITANIUM SUPPLY/DEMAND RELATIONSHIPS

Breadown of U.S. Titanium Consumption by Product Form

U.S. titanium consumption is segmented into titanium product forms in Figure G-1. In 1983, the primary usage of titanium was in the form of either 515,000 tons of titanium dioxide (49.2% of total consumption) or 523,000 tons of ilmenite ore (50% of total consumption) for pigment end-use. The more strategic and critical use of titanium metal consumes 8,000 tons of titanium metal.

Titanium: Supply/Demand Relationship-1983

A world supply/U.S. domestic demand relationship for titanium is shown in Figure G-2. As indicated, world production of titanium metal is estimated to be 75,000 tons of which the U.S. contributed 14,000 tons in 1983. World titanium mine production is estimated at 1.6 million tons. Where titanium metal imports for 1983 totalled 4,000 tons, imports of ilmenite ore, rutile, and pigment totalled 296,000 tons. Comparing the values in Figure G-1 with Figure G-2 indicates that around 50% of the total titanium metal demand is supplied by imports. Of the total U.S. demand for titanium (1.04 million tons) in 1983, around 24% was consumed by one economic sector-paints.

FIGURE G-1
Total U.S. Titanium Consumption-1983
(Thousands Short Tons)
(Ti Content)

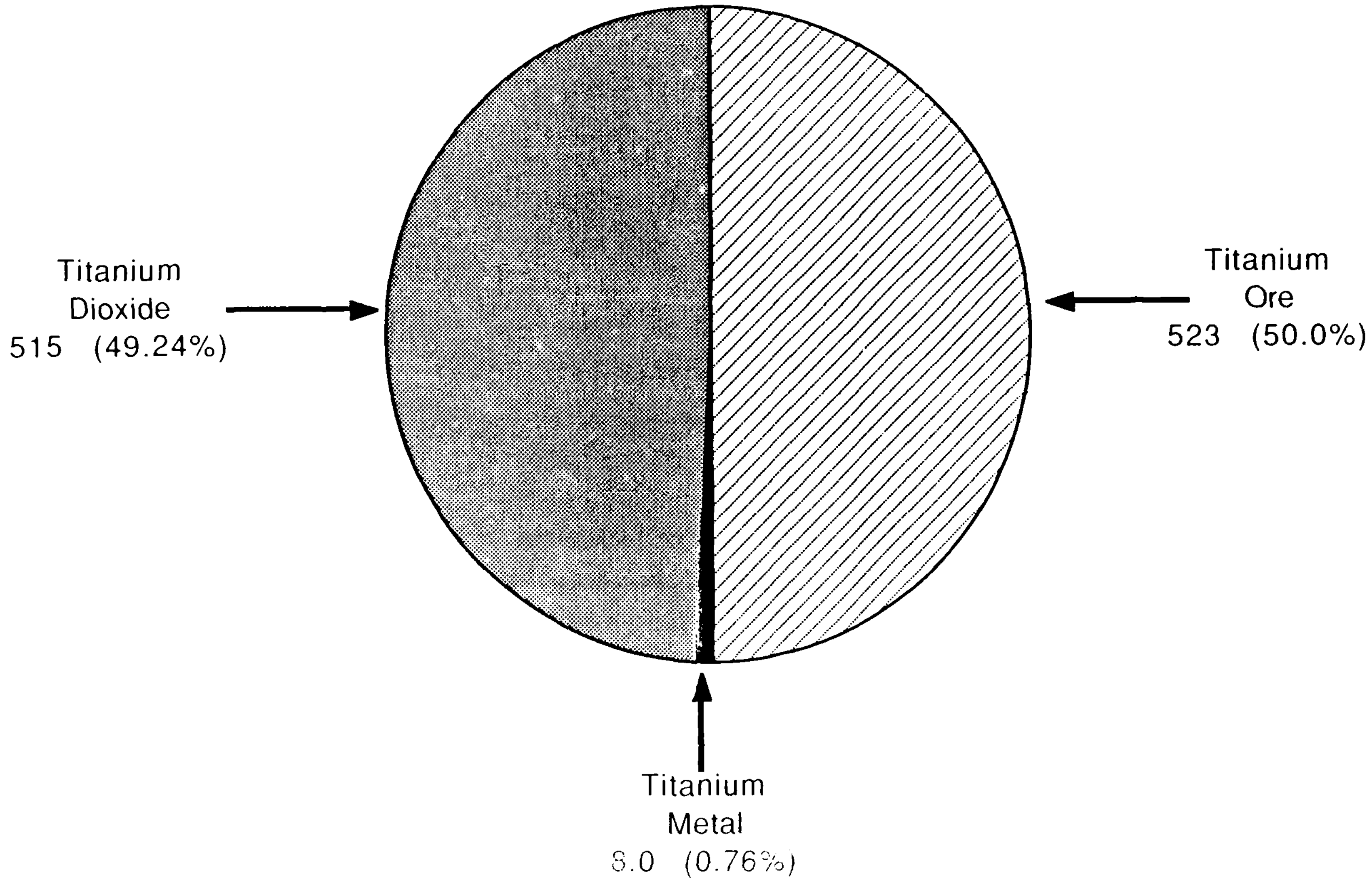
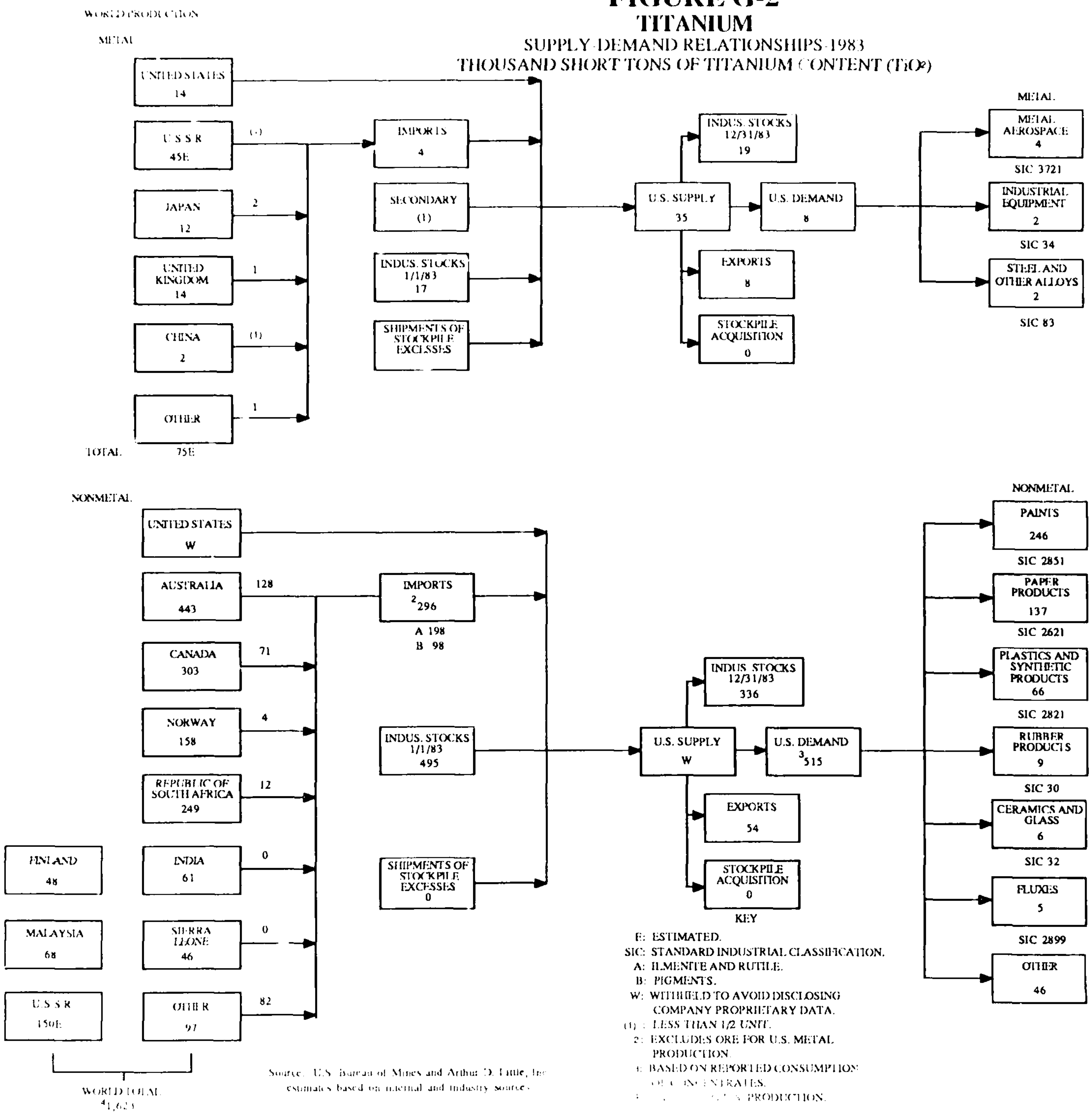


FIGURE G-2
TITANIUM
SUPPLY-DEMAND RELATIONSHIPS-1983
THOUSAND SHORT TONS OF TITANIUM CONTENT (TiO_2)



KEY

E: ESTIMATED.
SIC: STANDARD INDUSTRIAL CLASSIFICATION.
A: ILMENITE AND RUTILE.
B: PIGMENTS.
W: WITHHELD TO AVOID DISCLOSING COMPANY PROPRIETARY DATA.
(1): LESS THAN 1/2 UNIT.
2: EXCLUDES ORE FOR U.S. METAL PRODUCTION.
3: BASED ON REPORTED CONSUMPTION OF CONCENTRATES.
4: ... PRODUCTION.

Source: U.S. Bureau of Mines and Arthur D. Little, Inc. estimates based on internal and industry sources.

Titanium Domestic Supply/Demand Relationship: 1974-1984

A historical perspective of the United States dependence on foreign capacity to supply domestic demand is shown in Figure G-3. U.S. domestic production of titanium ore and sponge metal generally meet 50% or less of overall demand. In fact, sponge metal production generally meets U.S. industry demand with little or no excess production whereas U.S. ore mining meets less than 50% of total demand for this period.

Domestic Producers of Titanium Product-1986

U.S. producers of titanium metal sponge and ingot are listed in Table G-2. Titanium Metal Corp. in Henderson, Nevada and RMI Co. in Ashtabula, Ohio, Niles, Ohio, and Monroe, North Carolina are the largest producers in terms of capacity. Of the companies listed, four produce both sponge and ingot: International Titanium, Oregon Metallurgical Corp, RMI Co., and Titanium Metals Corp. of America.

U.S. producers of pigments are listed in Table G-3. There are four domestic producers with a gross annual capacity of 935,000 tons, 130,000 tons capacity based on the sulfate process and 805,000 tons based on the chloride process. Nearly 60% of the total pigment producing capacity in the U.S. is supplied by E.I. DuPont De Nemours & Co.

Recyle Flow for Titanium

A titanium scrap flow diagram depicting the general recyle flows are shown in Figure G-4. Scrap titanium metal accounts for around 35% to 40% of ingot production. Scrap is generally well-segregated by producers of ingots and mill products, and can therefore be allowed into the remelt stream for ingots and alloys. About one-third of the scrap generated by consumers of mill products in fabricated finished components is recyled. Scrap forms include chips, turnings, massive croppings and others. Up to 75% to 80% of ingot metal becomes scrap before being processed into finished parts.

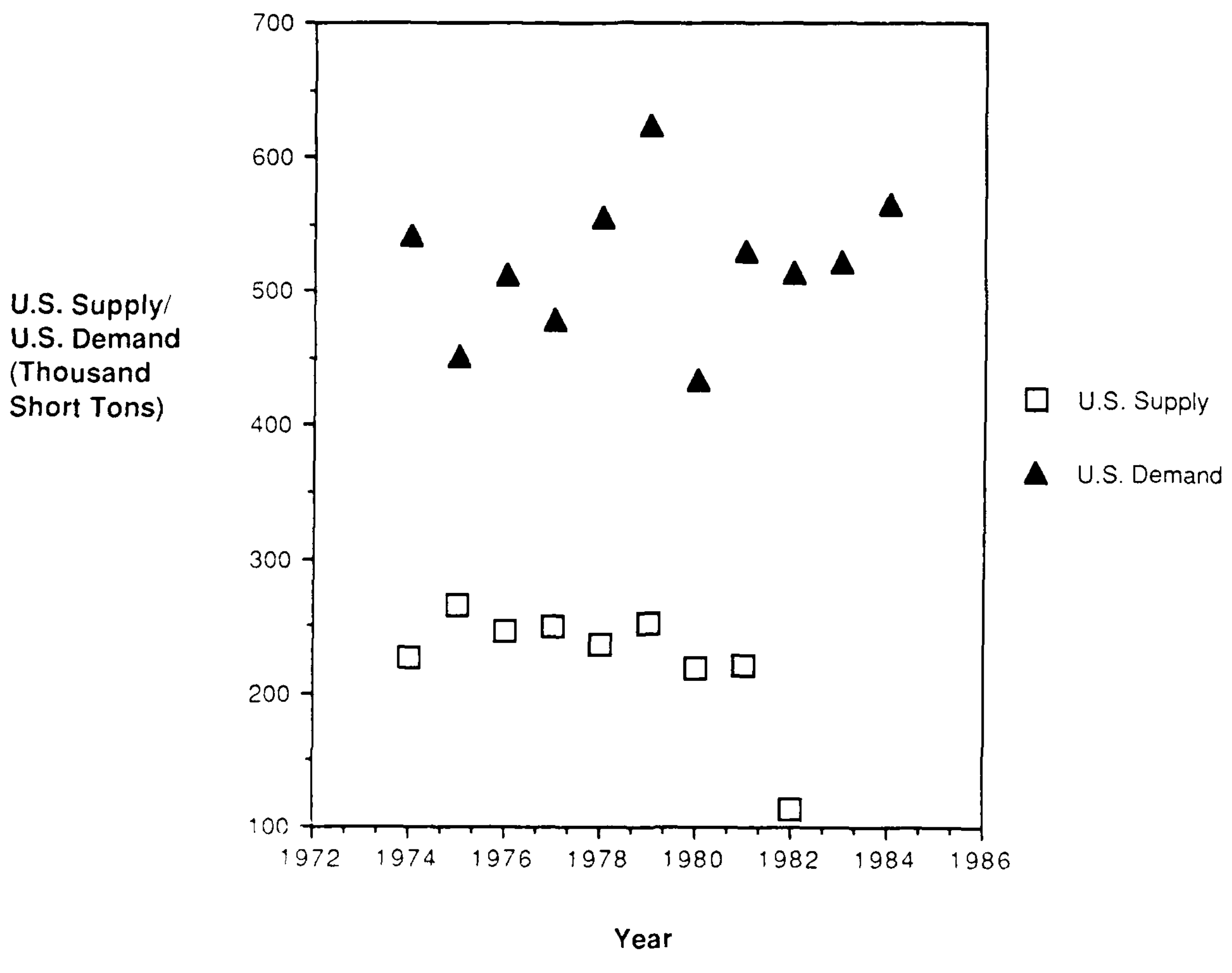
Estimated DOD-Related and Civilian Demand

Critical to this analysis of capacity/demand balance is the segmentation of total U.S. domestic demand (D_t) into its three components: Civilian demand (D_3), essential civilian demand (D_2), and estimated DOD demand (D_1). Analysis by Arthur D. Little, Inc., for FEMA using the INFORUM database converted domestic titanium demand in U.S. dollars to estimated tons of titanium for DOD and essential civilian end use. This analysis, an example of which is in Appendix A, further segmented domestic titanium demand into end-use economic sectors--aerospace, industrial equipment, steel and other alloys, ceramics and glass, fluxes, paints, paper products, plastics and synthetics, rubber products, and other.

Titanium Form Consumed for Each Economic Sector

In order to analyze the capacity/demand balance for a particular material process/product form, the percentage of various product forms being

FIGURE G-3
Titanium Metal and Nonmetal Supply-Demand Relationship, 1974-1984



Source: U.S. Bureau of Mines

TABLE G-2

DOMESTIC PRODUCERS OF TITANIUM METAL IN 1986

Company	Ownership	Plant Location	Capacity (short tons)	
			Sponge	Ingot
Howmet Corp., Titanium Ingot Div.	Pechiney, France.	Whitehall, MI		5,000
International Light Metals Corp.	Martin Marietta Corp., 60%; Nippon kokan K.K., 40%.	Torrance, CA		6,000
International Titanium Inc.	Wyman-Gordon Co., 80%; Mitsui & Co. Ltd., Japan, nearly 20%.	Moses Lake, WA	2,500	1,500
A. Johnson Metals Corp.	Axel Johnson Group, Stockholm, Sweden.	Lionville, PA		1,500
Lawrence Aviation Industries Inc.	Self	Port Jefferson, NY		8,000
Oregon metallurgical Corp.	Owens-Corning Fiberglas Corp., 80%; public, 20%.	Albany, OR	4,500	
RMI Co.	USX Corp., 50%; National Distillers & Chemical Corp., 50%.	Ashtabula, OH Niles, OH	9500	18,000
Teledyne Allvac	Teledyne Inc.	Monroe, NC		4,000
Teledyne Wah Chang Albany	do	Albany, OR		1,000
Titanium Metals Corp. of America	NL Industries Inc., 50%; Allegheny International Inc., 50%.	Henderson, NV	14,000	17,000
Viking Metallurgical Corp.	Quanex Corp.	Verdi, NV		5,000
Wyman-Gordon Co.	Self	Worcester, MA		2,500

Source: U.S. Bureau of Mines.

TABLE G-3

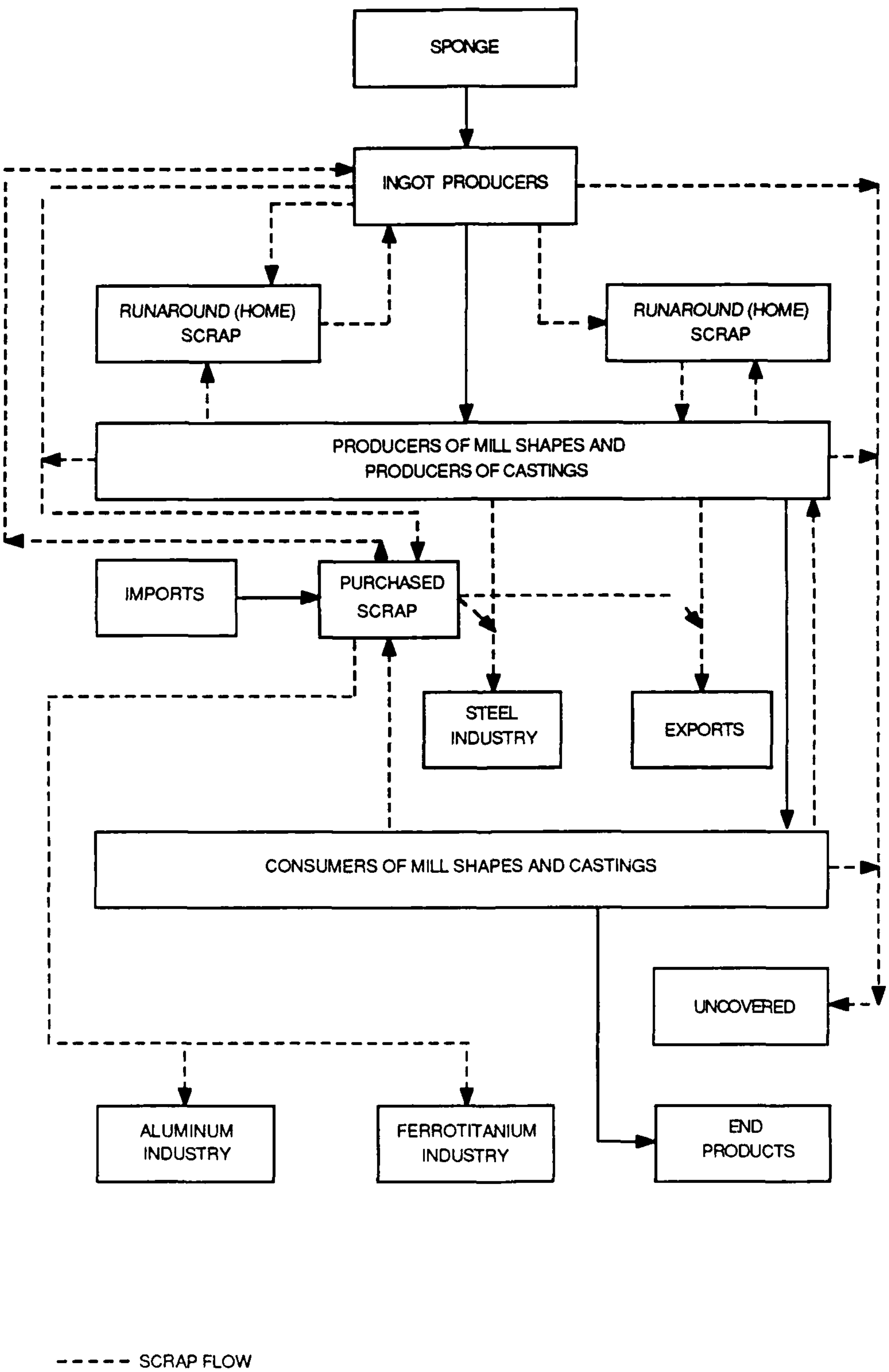
Capacities of U.S Titanium Dioxide Pigment Plants on December 31, 1986

Company and Plant Location	Pigment Capacity (short tons per year) Sulfate Process	Chloride Process
E. I. du Pont de Nemours & Co. Inc.:		
Antioch, CA	--	35,000
De Lisle, MS	--	150,000
Edge Moor, DE	--	110,000
New Johnsonville, TN	--	240,000
Kemira Inc., Savannah, GA	64,000	46,000
Kerr-McGee Chemical Corp., Hamilton, MS	--	72,000
SCM Chemicals Inc., Hanson Industries U.S.A.		
Ashtabula, OH	--	102,000
Baltimore, MD	66,000	50,000
Total	130,000	805,000

Source: U.S. Bureau of Mines.

FIGURE G-4

SCRAP-FLOW DIAGRAM FOR TITANIUM



Source: U.S. Bureau of Mines

supplied to particular end-use economic sectors must be estimated. In the case of titanium, there were three process/product forms to be analyzed:

- Mining/Ore
- Smelting or Reduction/Metal (including Ferroalloys)
- Chemical/Titanium Dioxide

Segmentation of total domestic demand in 1983 for each economic sector by titanium product form is shown in Figure G-5. In addition, the segmentation of total domestic demand into estimated DOD & essential civilian demand (D*) and civilian demand (D_3) allows the computation of titanium domestic demand on a process/product form basis also shown in Figure G-5.

TITANIUM CAPACITY ANALYSIS

Titanium vulnerability analysis data segmentation of total U.S. domestic titanium demand into estimated DOD and essential civilian demand categories in Appendix A, breakdown of U.S. titanium demand by process/product form in Figure G-5 along with supply and capacity estimates are compiled and consolidated in Table G-4. This data is used to generate U.S. domestic demand/domestic capacity ratios in Table G-5 to perform the capacity vulnerability analyses for titanium.

Titanium Vulnerability Analysis

Capacity vulnerability analysis charts for the production of titanium ore, titanium metal and titanium dioxide are shown in Figure G-6 through Figure G-8, respectively. A comparison of all titanium forms on one vulnerability chart is shown in Figure G-9. Titanium production capacity vulnerability has been segmented into five categories--not vulnerable, slightly vulnerable, vulnerable, very vulnerable, and extremely vulnerable as indicated in Table G-6. Titanium ore mining capacity falls into the "vulnerable" category. Ore is the only titanium product form from this analysis that has a degree of capacity vulnerability. For both peactime and increased (2X,3X, and 4X) demand scenarios both titanium metal and titanium dioxide forms fall into the "not vulnerable" region. No historical data was obtained through open sources for the production capacity of these titanium process/product forms.

TITANIUM CAPACITY ANALYSIS SUMMARY

Even though the U.S. has recently supplied approximately one-third of its ilmenite ore consumption, domestic metal and rutile producers have chosen, largely on economic grounds, to import high grade ore. Domestic production capacity is rated at 214,000 tons of ore to supply a total demand of around 523,000 tons of which only an estimated 5,000 tons is DOD and essential civilian demand.

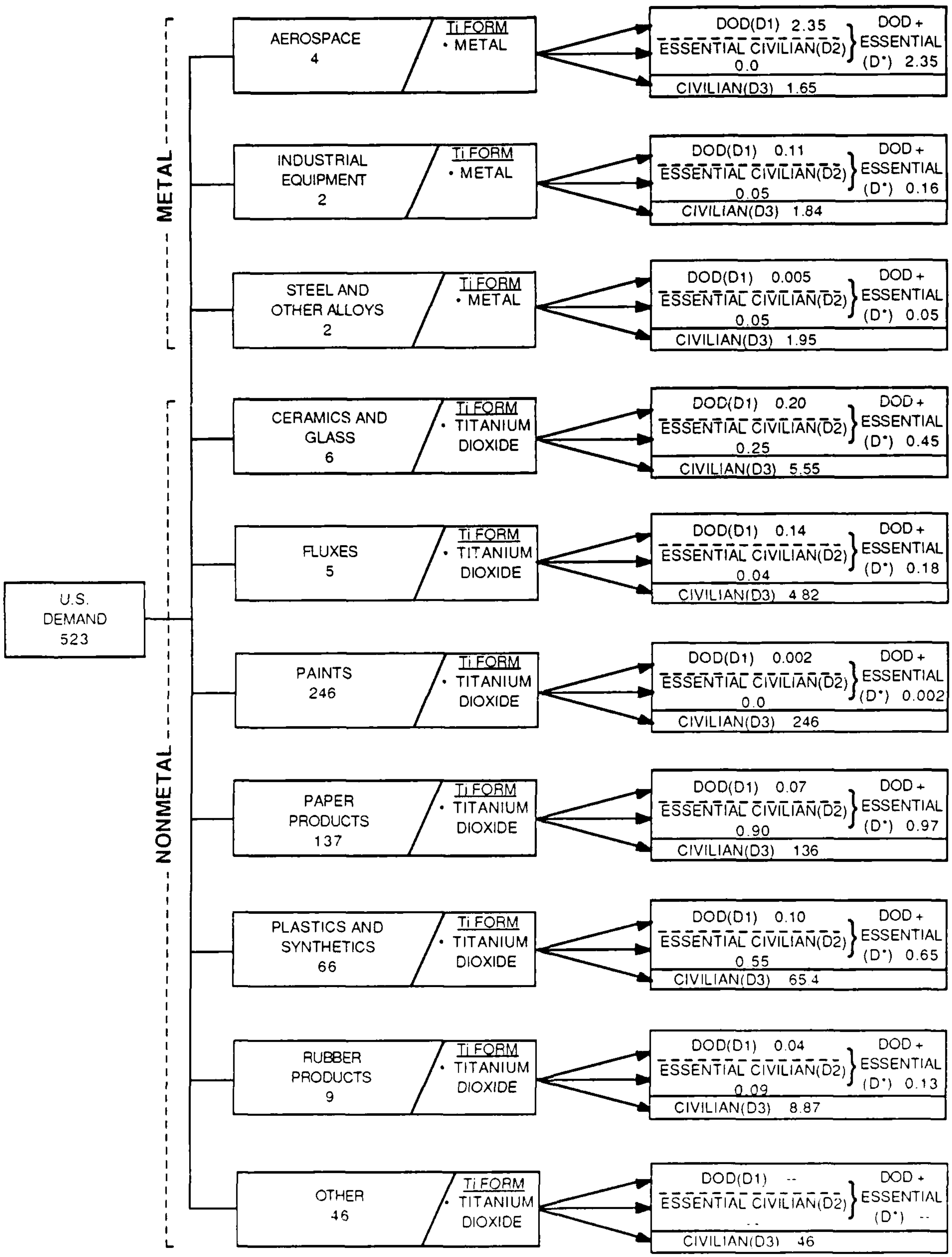
The U.S. consumes around 20% of the total foreign supply of titanium ore (in TiO_2 content) but produces less than 10% of worldwide supply. Looking at the titanium product form flowsheet in Figure G-10 the capacity

FIGURE G-5

U.S. TITANIUM DEMAND BREAKDOWN (1983)

(THOUSAND SHORT TONS)

(Ti Content)



Source: U. S. Bureau of Mines and Arthur D. Little, Inc.
Estimates based on Inforum Data

TABLE G-4
TITANIUM VULNERABILITY INDEX DATA

Thousand Short Tons per Year
(TiO_2 Content)

TITANIUM		TOTAL Ti DEMAND (D_T)	DOD & ESSENTIAL CIVILIAN DEMAND (D)	EXISTING & CONVERTIBLE DOMESTIC CAPACITY (C)	DOMESTIC SUPPLY (S)	NON-DOMESTIC SUPPLY (1983)	CIVILIAN DEMAND (D_3)
PRODUCT FORM	PROCESS STAGE						
ORE	MINING	523	4.94	214	W	2427 •	518.08
METAL	ELECTROLYTIC REDUCTION	8.0	2.56	34 (2)	14 •	132 •	5.44
TITANIUM DIOXIDE	CHEMICAL	515	2.38	550	455 •	1778 (1)	512.64

Source: U.S. Bureau of Mines

e: Arthur D. Little estimates based on internal and industry sources.

N.A.: Not applicable

(1): Synthetic rutile and pigment

(2): Only Ti sponge

W: Witheld to avoid revealing proprietary data

TABLE G-5

TITANIUM DOMESTIC DEMAND/ DOMESTIC CAPACITY RATIOS

	PEACE TIME		INCREASED DEMAND		
			2X	3X	4X
	$\frac{D_3}{C}$	$\frac{D^*}{C}$	$\frac{2D^*}{C}$	$\frac{3D^*}{C}$	$\frac{4D^*}{C}$
Ore Mining	2.42	0.023	0.046	0.069	0.092
Metal	0.16	0.075	0.15	0.225	0.30
Titanium Dioxide	0.93	0.0043	0.0083	0.013	0.017

FIGURE G-6

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Titanium Ore Mining

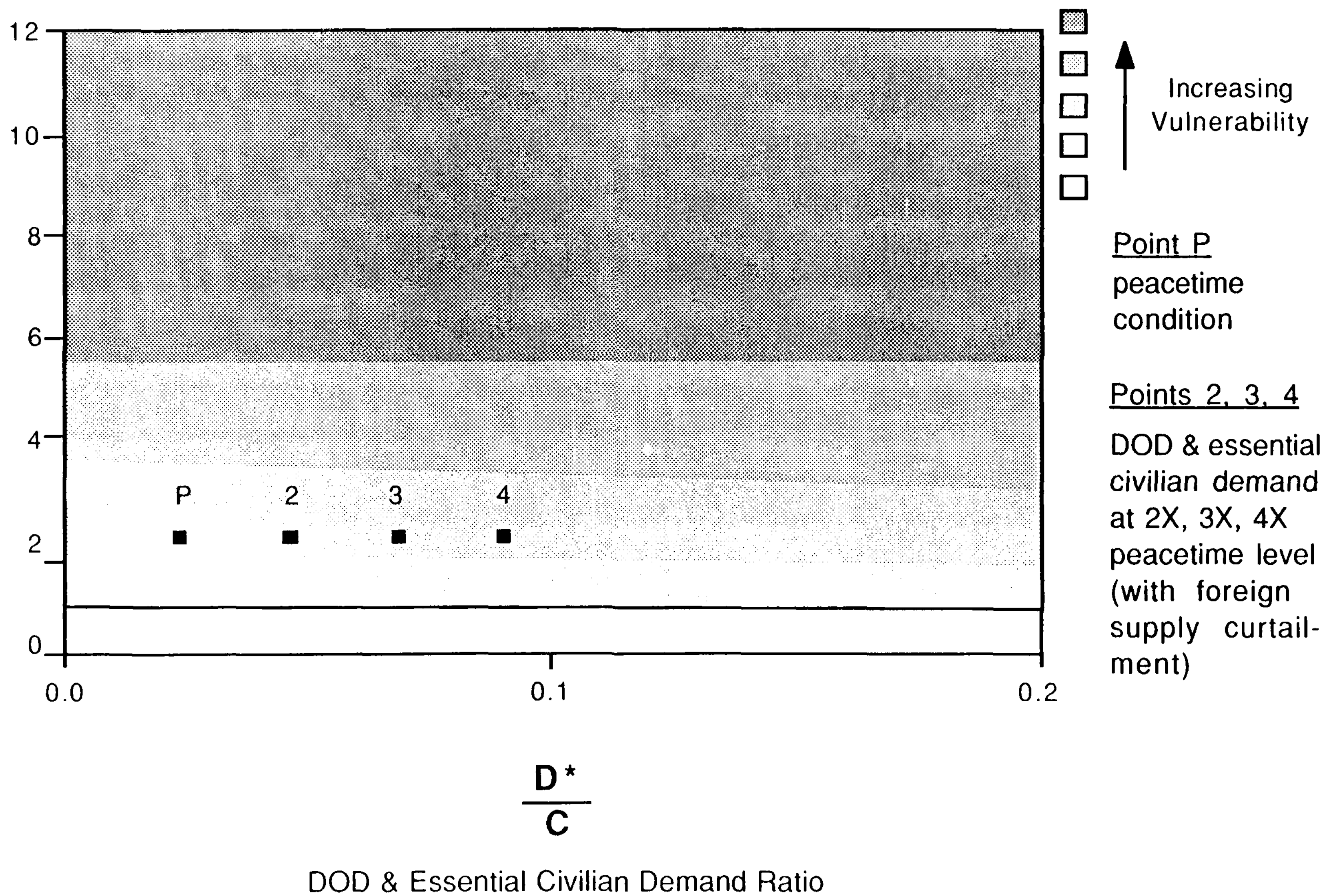


FIGURE G-7

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Titanium Metal

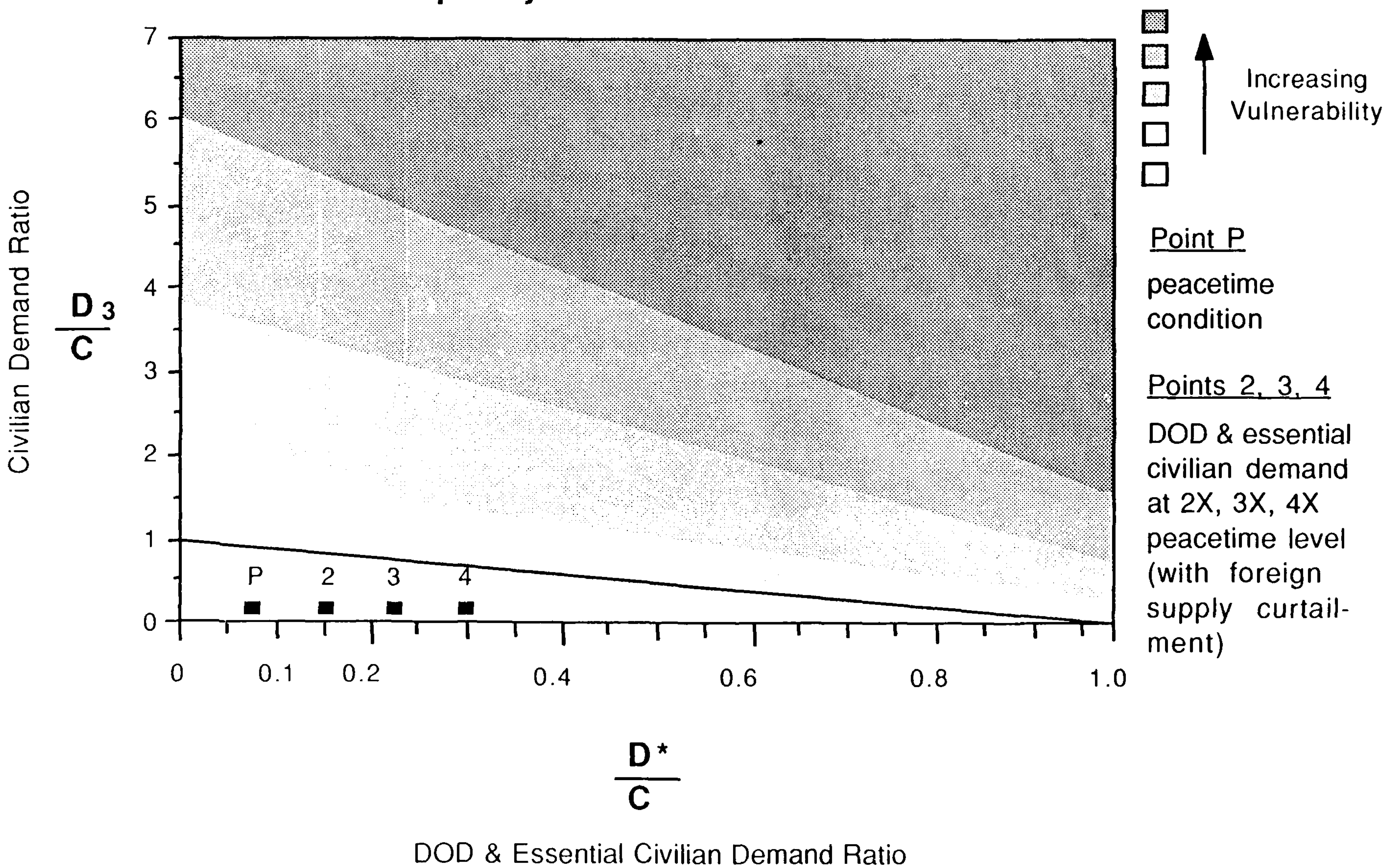


FIGURE G-8

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Titanium Dioxide

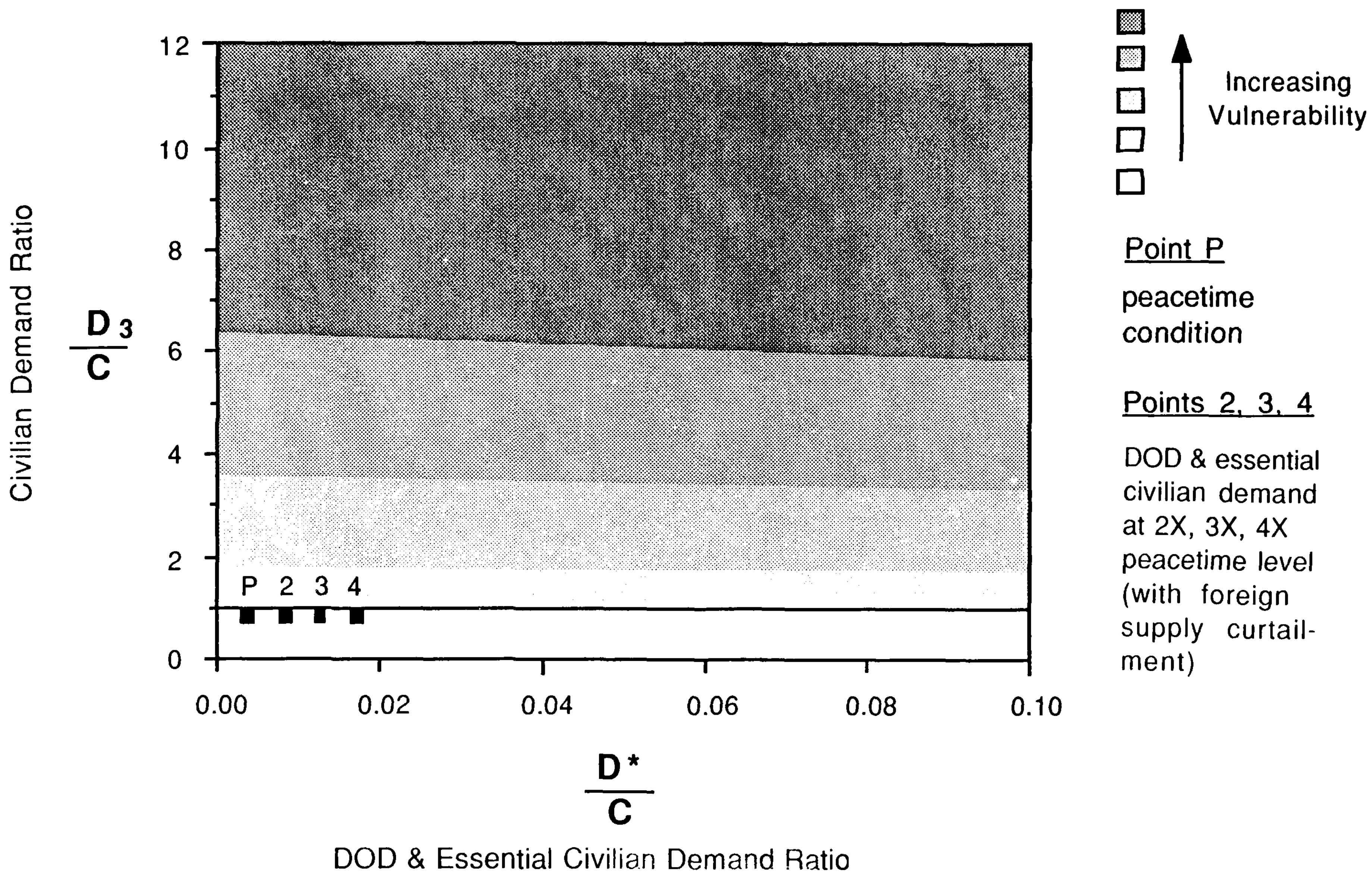


FIGURE G-9
VULNERABILITY ASSESSMENT
Process Form Comparison for Titanium

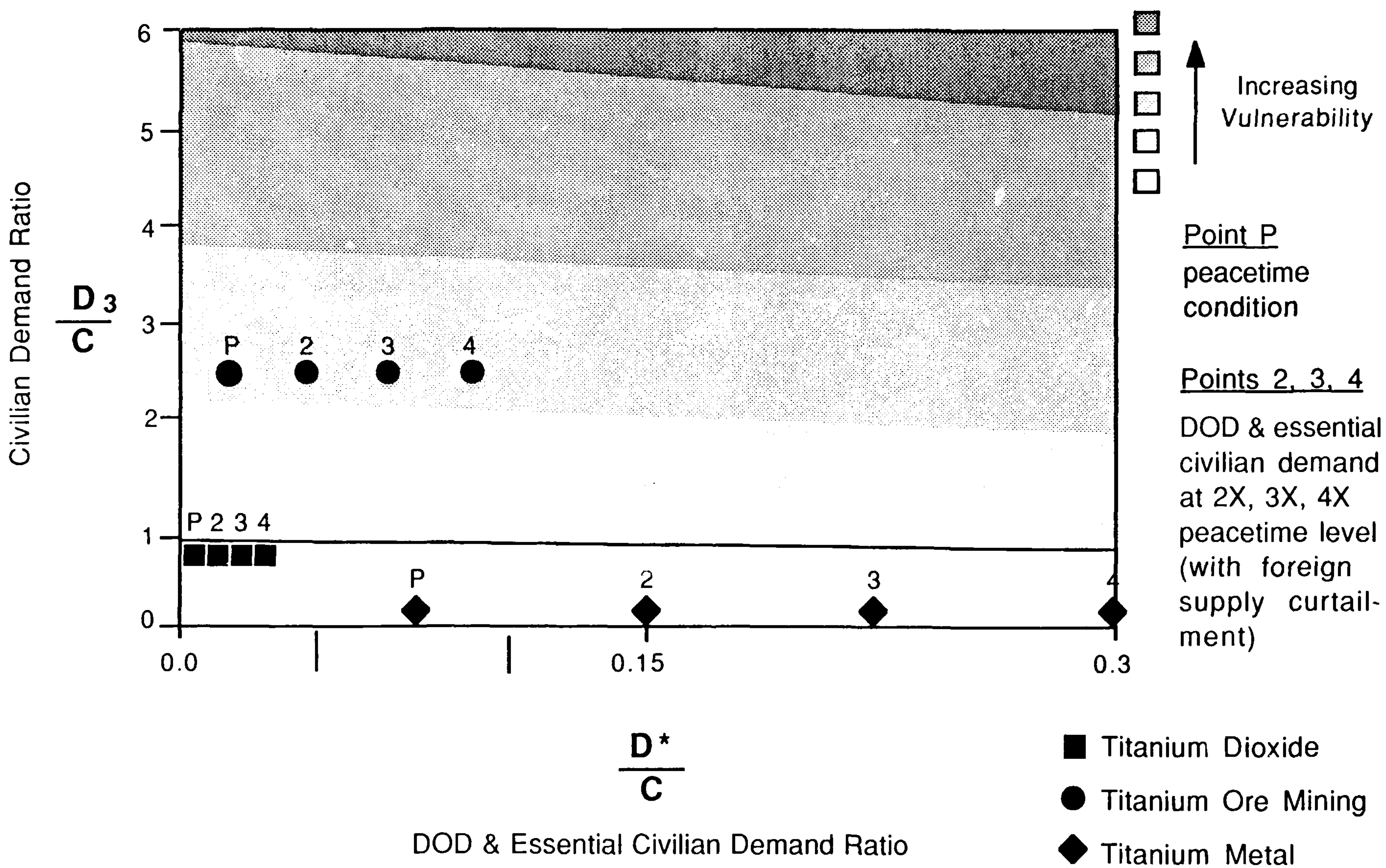


TABLE G-6
TITANIUM DOMESTIC CAPACITY ANALYSIS SUMMARY
RELATIVE VULNERABILITY INDEX

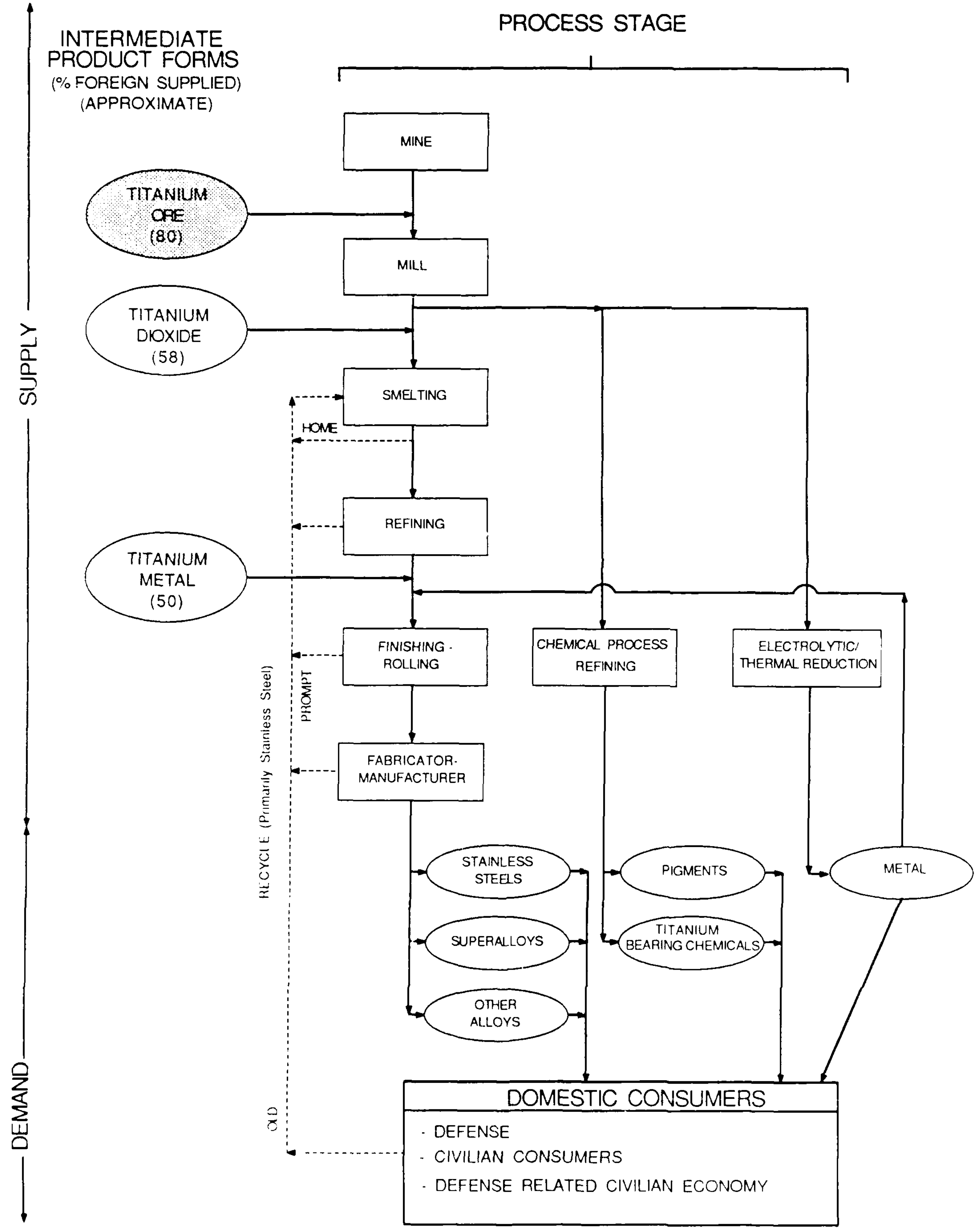
TITANIUM

INCREASING VULNERABILITY →

PROCESS	PRODUCT FORM	NOT VULNERABLE	SLIGHTLY VULNERABLE	VULNERABLE	VERY VULNERABLE	EXTREMELY VULNERABLE
MINING	ORE			P, 2, 3, 4		
ELECTROLYTIC REDUCTION	METALS	P, 2, 3, 4				
CHEMICAL	TITANIUM DIOXIDE	P, 2, 3, 4				

P - PEACETIME
2 - DEMAND (2X PEACETIME DEMAND)
3 - DEMAND (3X PEACETIME DEMAND)
4 - DEMAND (4X PEACETIME DEMAND)

FIGURE G-10
TITANIUM PRODUCT FORM FLOWSHEET



"pinchpoint" is obviously near the front-end of the supply process. This flowsheet brings the various components of supply and demand together in one figure to emphasize the downstream impact of process/product capacity "pinchpoints". Both the production capacity of titanium metal and titaniuim dioxide are estimated to be in excess of both domestic civilian, estimated DOD, and essential civilian demand requirements. Recent production capacity fig' res for pigment show a capacity near 1.1 million tons per year.

REFERENCES

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APPENDIX H

PLATINUM GROUP INDUSTRY STRUCTURE

Overview

The platinum group comprises six closely related metals: platinum, palladium, rhodium, ruthenium, iridium, and osmium, which commonly occur together in nature and are among the scarcest of the metallic elements. Along with gold and silver, they are known as precious or noble metals. They occur as native alloys or mineral compounds in placer deposits, sometimes associated with gold. In lode deposits, they are commonly associated with nickel and copper. Nearly all of the world's supply of these metals currently are extracted from lode deposits in three countries - the Republic of South Africa, the U.S.S.R., and Canada.[1]

The platinum-group metals (PGM) have become critical to industry because of their extraordinary physical and chemical properties. In the United States, over 95% of the PGM consumed each year is by industry. The metals are refractory, are chemically inert at elevated temperatures to a wide variety of materials, and display excellent catalytic activity. These properties are the basis for the principal uses - as catalysts in the automotive, chemical, and petroleum refining industries, and as corrosion-resistant materials in the chemical, electrical, glass, and dental-medical industries.[1]

Of the annual U.S. supply of PGM, about 7% is secondary metal, recycled or reclaimed mainly from domestic sources; and 93% is primary, or newly mined, metal, virtually all of which is imported. U.S. mine production is a by-product of copper production. Other countries producing small amounts of by-product PGM from native ores include Australia, Finland, Yugoslavia, and Zimbabwe. Japan produces by-product PGM from imported ores. Colombia and Ethiopia produce a small quantity of platinum from placer deposits.

In Appendix H, an analysis of U.S. domestic capacity for the production of platinum group product forms consumed will be compared against U.S. segmented demand to evaluate capacity vulnerability.

Geographic Distribution

The South African mines are located in the Bushveld Igneous Complex, near the town of Rustenburg. Platinum is the main product, and all other metals in the platinum group are by-products. Rustenburg Platinum Holdings Ltd. is the largest platinum producer, followed by Impala Platinum Holdings Ltd. and Western Platinum, Ltd. Estimated platinum production by these companies in 1983, in thousand troy ounces, was 800,670, and 130, respectively.

In Canada, PGM are all by-products of nickel-copper mining by INCO Ltd. and Falconbridge Ltd. The mines are located at Sudbury, Ontario, and Thompson, Manitoba. Estimated 1983 production of platinum by INCO was 50,000 ounces, while Falconbridge production was 20,000 ounces.

The U.S.S.R. is the world's principal palladium producer and second largest platinum producer. About 85% to 90% of the U.S.S.R.'s PGM production is a by-product of nickel-copper mining near the city of Noril'sk, in Siberia.

The balance comes from nickel-copper mining in the Kola Peninsula, near Finland and Norway, and from placer deposits in the Ural Mountains.

Refining of PGM scrap is quite extensive worldwide. In the United States, major secondary refineries are concentrated on the east and west coasts. Some of the larger ones are Johnson Matthey Inc. and AMAX Copper Inc. in New Jersey, and Gemini Industries Inc. and PGP Industries Inc. in California. Engelhard Corp. closed its refining facility in New Jersey in 1983.[2] About 20 to 30 refiners handle or process in some way domestic PGM scrap; however, most refiners treat only platinum and palladium, and only a few routinely separate and refine all six metals.

Most major refiners tend to be vertically integrated, either owning or having direct access to mines, refineries, fabrication plants, manufacturing plants, and trading and marketing departments.[1]

Grades and Specifications

Metals of the platinum group are bought and sold in troy ounces or, in markets where the metric system prevails, in grams or kilograms. Platinum and palladium are traded on the New York Mercantile Exchange in units of 50 and 100 troy ounces, respectively. On the New York Exchange, platinum must contain at least 99.9% platinum, and palladium, at least 99.8% palladium. Metallic platinum and palladium are available in many basic forms, including powder, single crystals, sponge, sheet, ribbon, foil, bars, plate, and wire. Sponge is a term applied to an imperfectly consolidated metal, the end product of chemical refining. Rhodium, iridium, osmium, and ruthenium are available as powder and in several compact forms. All metals of the group are available as salts.[3]

The purity required for various uses has risen over the years until, at present, commercial-grade platinum normally must be at least 99.95% pure, and palladium, 99.9% pure. Platinum at least 99.999% pure is considered chemically pure and is the grade required for thermocouples and resistance thermometers.

According to Federal regulations, articles made wholly or in part of platinum must contain a minimum of 95% platinum to be called "platinum." [4] Special stamping provisions cover some alloys developed for the jewelry trade. In the United Kingdom, all platinum jewelry sold must have 95% platinum content to be hallmarked.

INDUSTRIAL APPLICATIONS

Overview

The uses of the PGM are related to their extraordinary catalytic activity, chemical inertness over wide temperature ranges, and high melting points. In dome applications, it is the combination of two or more of these characteristics, rather than any one alone, that makes the PGM uniquely useful.

Since 1974, platinum-palladium oxidation catalysts have been used to reduce the emission of carbon monoxide and hydrocarbons from automobiles and

light-duty trucks. These catalysts employ a small amount of rhodium in the reduction chamber. A typical three-way automotive catalyst produced in 1981 contained 0.05 ounce platinum, 0.02 ounce palladium, and 0.005 ounce rhodium.[5]

The organic catalytic uses of PGM include the oxidation of ammonia to give nitric acid, the synthesis of hydrogen cyanide, and the production of hydrogen peroxide. Hydrogen cyanide is made using a catalyst in the form of a given alloy gauze consisting of 90% platinum and 10% rhodium. Hydrogen cyanide is an intermediate for the production of insecticides, sodium and potassium cyanide, and some transparent plastics. Organic chemicals produced using PGM catalysts include vinyl acetate, cyclohexane, ethylene and propylene, caprolactam, and aniline. Organic pharmaceuticals are also produced using PGM catalysts. For example, a common nonprescription pain reliever is produced using a platinum catalyst; and vitamins A and B_2 are synthesized with palladium catalysts. Noncatalytic uses of PGM in the chemical industry include thermocouples, thick film resistance temperature detectors, laboratory ware, and rupture disks.

The major use of PGM in the petroleum industry is for refining, particularly catalytic reforming, which is one of the processes by which naptha is upgraded to high-octane gasoline. Most commonly, reforming is accomplished by using bimetallic platinum and rhenium or platinum and iridium catalysts. Hydrocracking, another refining process, involves using a palladium catalyst to increase gasoline yields by adding hydrogen under pressure.[1]

In the ceramics and glass industry, PGM are used for their ability to withstand high temperatures and corrosive environments. The most important application for PGM in this area is for making glass fibers. There are two basic types of glass fibers--a woollike variety and a textile filament type. The woollike variety is produced by flowing molten glass through tiny holes in a rapidly rotating vessel called a spinner, which is made of a PGM alloy. The filament-type fibers are produced by mechanically stretching out streams of molten glass flowing from tiny holes in a stationary vessel called a bushing, which is also made of a PGM alloy.

A major use of palladium is in low-voltage electrical contacts, containing 60% palladium and 40% silver, for telephone switching. More recently, alloys of 80% palladium and 20% nickel have been used as electrical contacts. The metals platinum, rhodium and iridium are used in thermocouples and furnace heater windings; palladium and silver alloys are used in capacitors; and ruthenium, platinum, and iridium are used in anodes for the electrolytic production of chlorine and sodium hydroxide from brine.[1]

Palladium is used for its tarnish resistance and platinum for hardening in dental applications such as crowns and bridges and alloys for porcelain veneers. These metals are usually alloyed with varying proportions of silver, gold, and copper. Medical uses include the use of PGM compounds in the treatment of cancer, osmium tetroxide in the treatment of inflammatory arthritis, and radioactive implants using iridium in the control of tumors.

The most popular PGM alloy for jewelry use is 95% platinum and 5% ruthenium. Also used is 90% platinum and 10% iridium, and in Europe, 96% platinum and 4% palladium.[1]

Substitution Technology

In automotive catalysts, platinum, palladium, and rhodium are so efficient that they have had no competition from substitutes in recent years. In the chemical and petroleum industries, there is little incentive to substitute other metals for PGM catalysts, inasmuch as losses from recycling are very low and the cost of PGM is low in comparison to the value of the end products produced. This is particularly true for pharmaceuticals. Even when substitution is possible, there usually are severe sacrifices in efficiency.

Another important consideration in substituting one catalyst for another is that modification of a plant may be required.[6] Each plant is designed to operate at temperatures and pressures that may be unique for the catalyst used.

Silver and gold substitute for platinum and palladium in electrical end uses. Tin-lead alloys are being investigated as a possible substitute for precious metals in electronic uses.

In dental applications, gold-palladium and palladium-silver alloys produce superior physical restorations; however, the silver-gold-copper alloys formerly used remain as possible alternatives.[1]

PLATINUM SUPPLY/DEMAND RELATIONSHIPS

Breakdown of U.S. Platinum Group Consumption by Product Form

U.S. PGM consumption is segmented into PGM product forms in Figure H-1. Virtually all PGM is used in a metallic state. For this analysis, PGM has been segmented into three categories: platinum group used in a catalytic end-use, platinum group used as a metal (non-catalytic), and PGM other. These groupings are arbitrarily set to facilitate the vulnerability analysis. PGM (catalytic) accounted for 954,000 troy ounces (49.84% of total demand) while PGM metal (non-catalytic) accounted for 806,000 troy ounces (42.11% of total demand) in 1983.

Platinum: Supply/Demand Relationship-1983

A world supply/U.S. domestic demand relationship for PGM is shown in Figure H-2. As indicated, world production of PGM is estimated to be 6.4 million troy ounces of which the U.S. contributed 6,000 troy ounces in 1983. U.S. supply in 1983 was 4.19 million troy ounces of which domestic consumption accounted for around 1.9 million troy ounces. This consumption is segmented into eight economic sectors: automotive, chemicals, petroleum, ceramics and glass, electrical and electronic, dental and medical, jewelry and decorative, and other. Around 58% of domestic consumption (1.1 million troy ounces) is consumed in two economic sectors: automotive and electronics.

Figure H-1
Total U.S. Platinum Group Consumption 1983
(Thousands Troy Ounces)

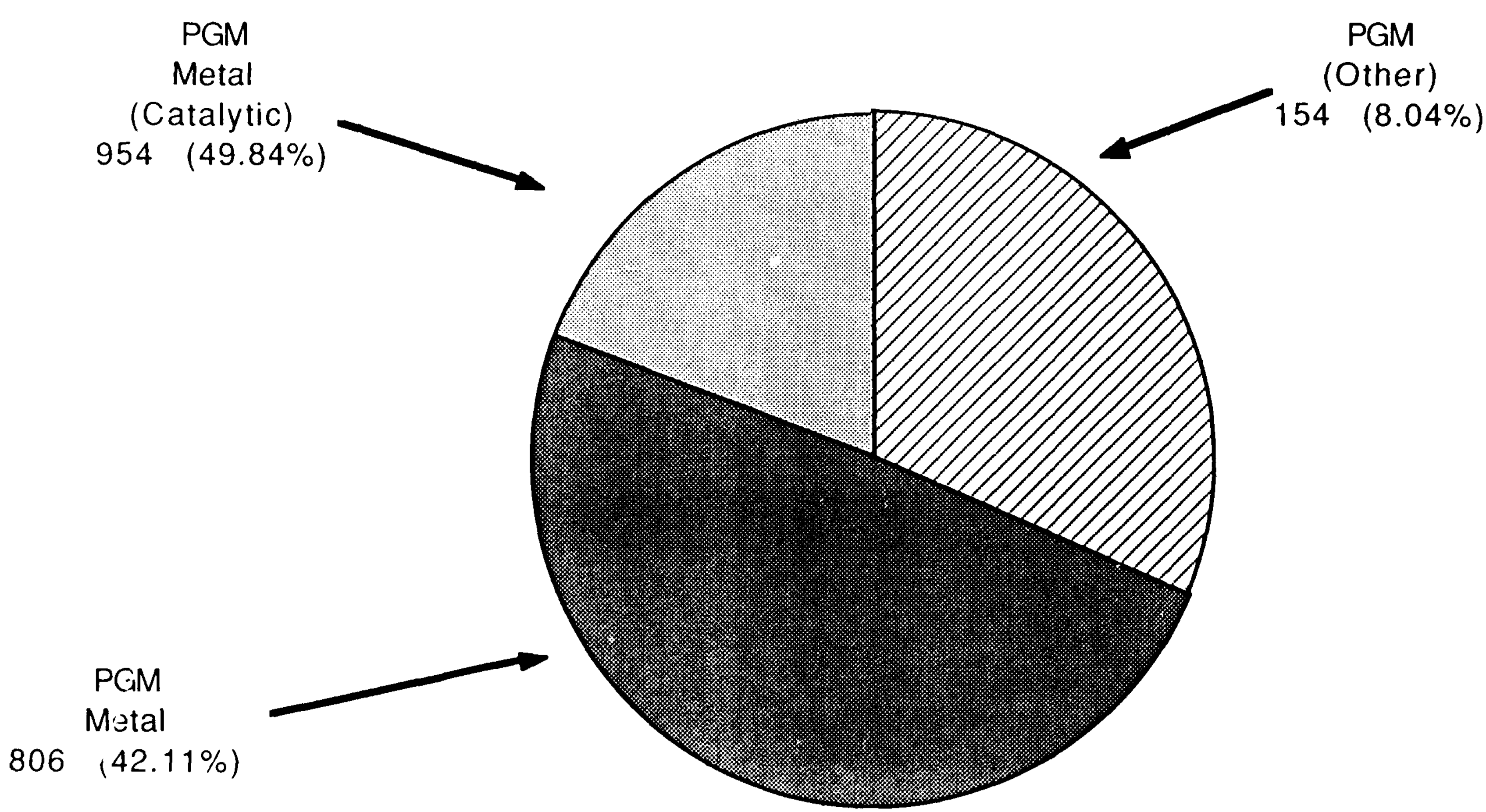
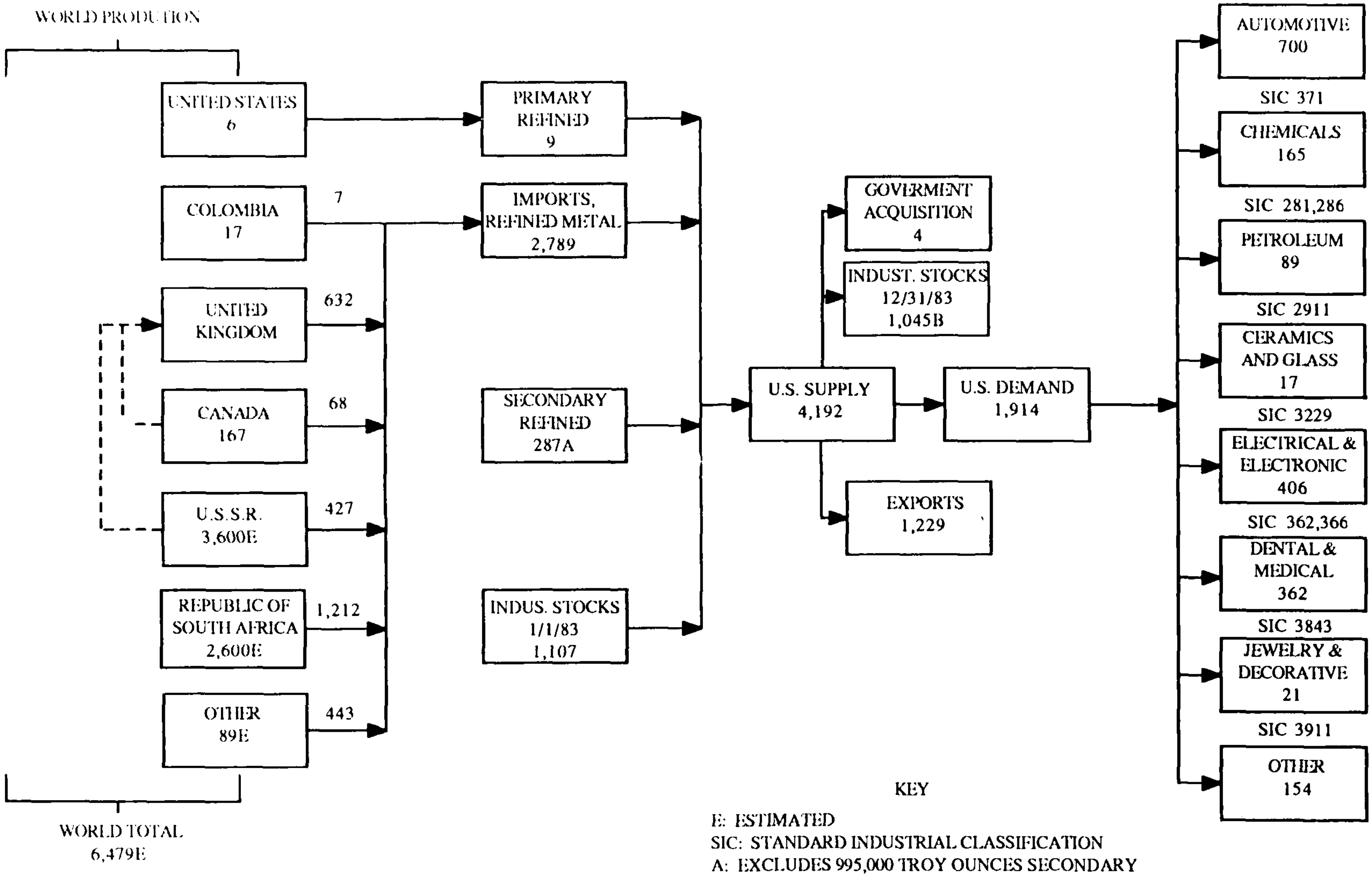


FIGURE II-2
PLATINUM GROUP

SUPPLY-DEMAND RELATIONSHIPS-1983
THOUSAND TROY OUNCES OF PLATINUM-GROUP METALS



KEY

E: ESTIMATED
SIC: STANDARD INDUSTRIAL CLASSIFICATION
A: EXCLUDES 995,000 TROY OUNCES SECONDARY TOLL-REFINED METAL
B: INCLUDES UNACCOUNTED FOR SURPLUS

Source: U.S. Bureau of Mines and Arthur D. Little, Inc. estimates based on internal and industry sources.

Platinum Domestic Supply/Demand Relationship: 1974-1984

A historical perspective of the United States dependence on foreign capacity to supply PGM is shown in Figure H-3. U.S. domestic production (primary and secondary refined) of PGM generally meet less than 20% of total domestic demand. In fact, with U.S. mine production of only 6,000 troy ounces in 1983, and few high-grade PGM deposits in the U.S., this supply/demand trend will continue.

Domestic Producers of Platinum Group Product-1986

U.S. production of primary PGM is extremely small and consists almost entirely of platinum and palladium produced from electrolytic sludges of three major copper refineries. The refineries are those of U.S. Metals Refining Co. (subsidiary of AMAX Inc.) in New Jersey, ASARCO Incorporated in Texas, and Kennecott in Utah.

Recycle Flow for Platinum

PGM are recovered principally from petroleum catalysts, chemical catalysts, and glass fiber bushings. Smaller amounts are recovered from used and new automotive catalytic converters, electronic scrap, jewelry, laboratory crucibles, and dental materials. A scrap flow diagram for PGM is shown in Figure H-4.

Nearly all PGM-containing chemical and petroleum catalysts are recycled periodically. About 85% of the PGM in recycled chemical and pharmaceutical catalysts is recovered, versus about 97% of the PGM in petroleum refining catalysts.

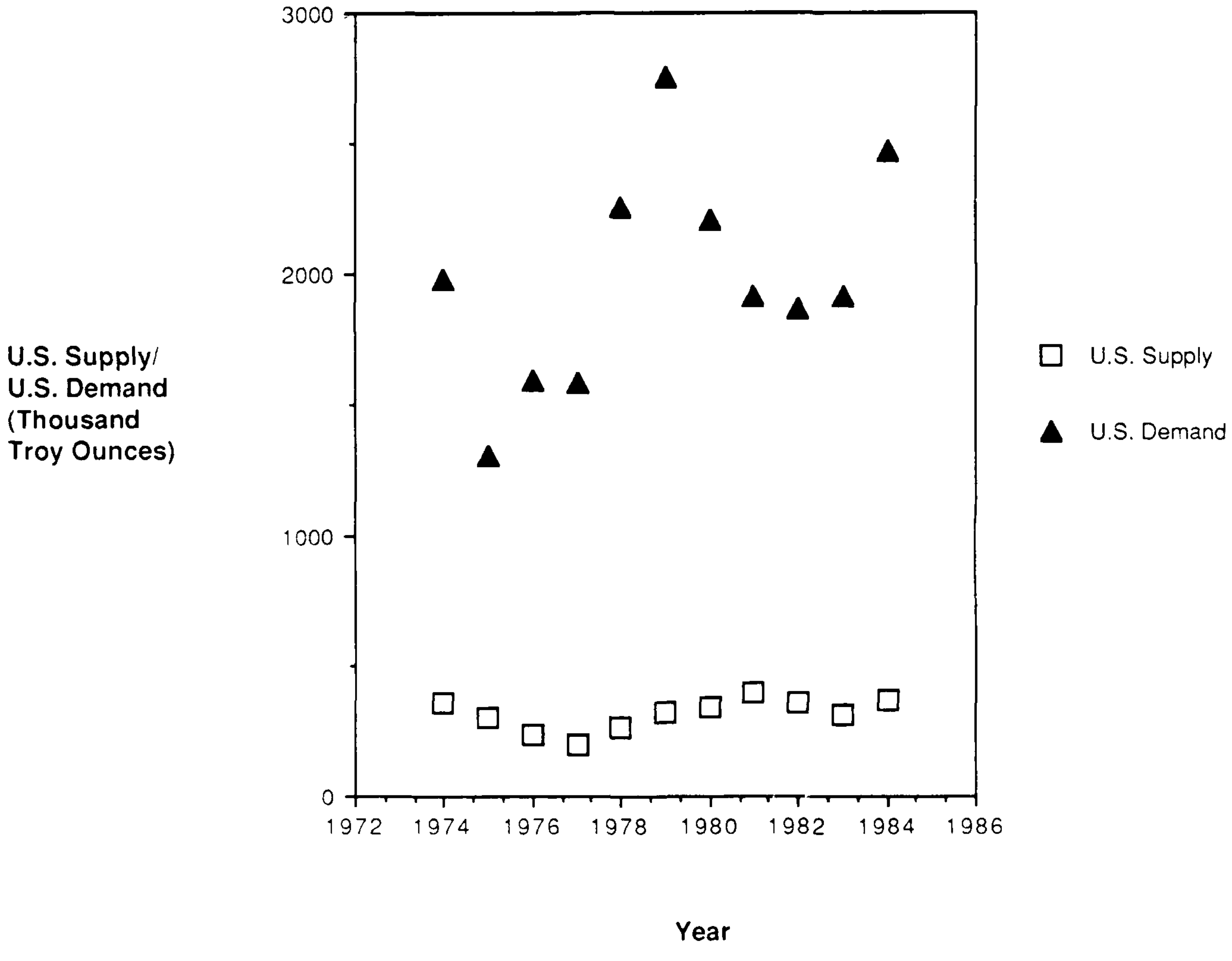
Recycling of used automotive catalysts is very low in comparison to the quantity of scrapped catalysts available. Auto catalysts represent one of the lowest grade sources of secondary PGM. Over 5 million troy ounces of PGM have been purchased by the U.S. automobile industry for use in catalysts from 1974 to 1983, most of which is still contained in operating vehicles.

Since October 1974, the Department of Defense (DOD) has operated a program that provides for the recovery of platinum and other precious metals from Government-owned film, circuit boards, photographic solutions, and other materials. [1]

Estimated DOD-Related and Civilian Demand

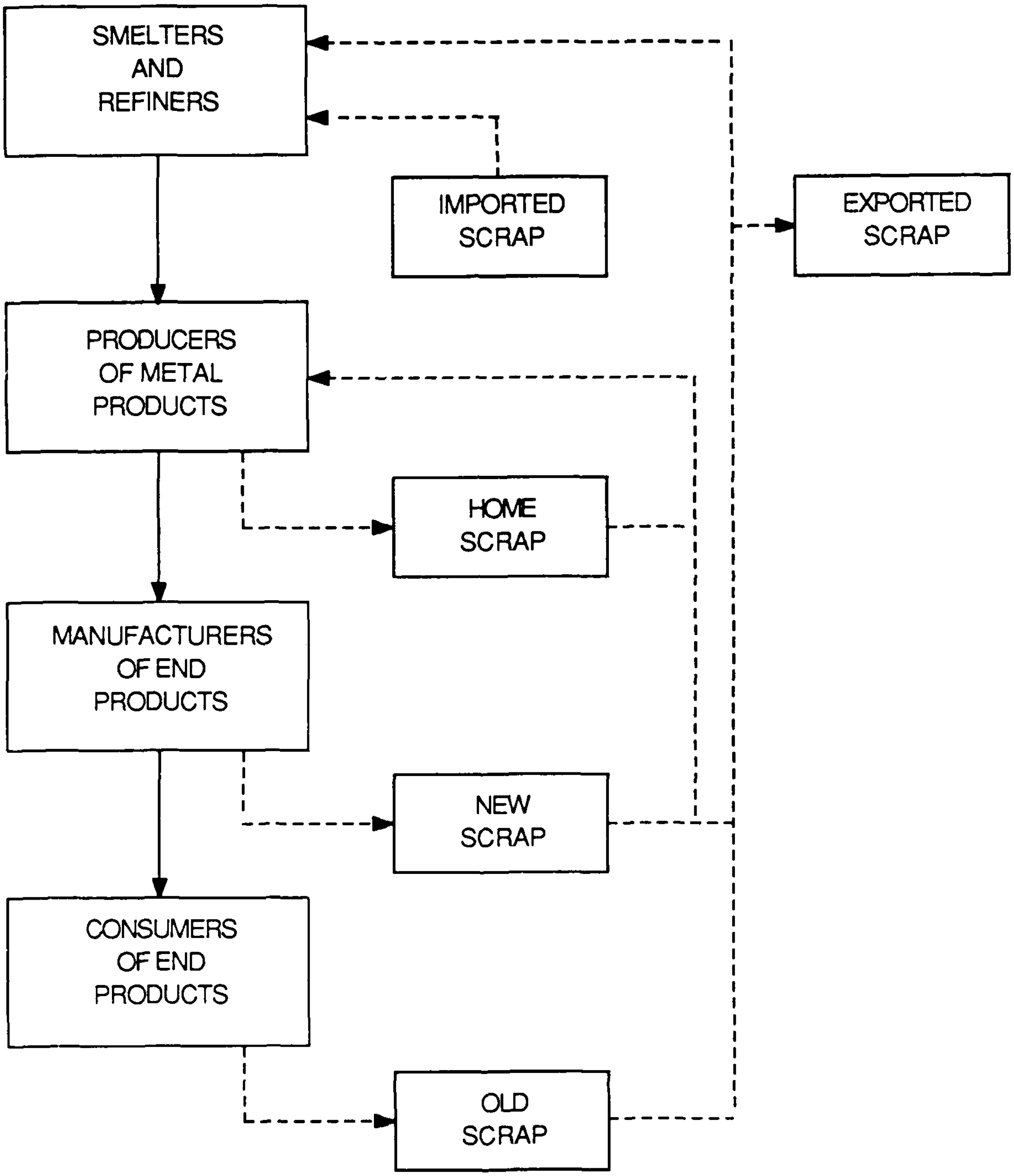
Critical to this analysis of capacity/demand balance is the segmentation of total U.S. PGM domestic demand (D_t) into its three components: Civilian demand (D_3), essential civilian demand (D_2), and estimated DOD demand (D_1). Analysis by Arthur D. Little, Inc., for FEMA using the INFORUM database converted domestic PGM demand in U.S. dollars to estimated troy ounces of PGM for DOD and essential civilian use. This analysis for PGM, an example of which is in Appendix A, further segmented domestic PGM demand into end-use economic sectors--automotive, electrical and electronics, chemical, petroleum, dental and medical, glass and ceramics, jewelry and decorative, and other.

FIGURE H-3
Platinum Group Metals Domestic Supply-Demand Relationship, 1974-1984



Source: U.S. Bureau of Mines

FIGURE H-4
SCRAP-FLOW DIAGRAM FOR PLATINUM GROUP



Platinum Group Form Consumed for Each Economic Sector

In order to analyze the capacity/demand balance for a particular material process/product form, the percentage of various product forms being supplied to particular end-use economic sectors must be estimated. In the case of PGM, there were three process/product forms to be analyzed:

- Mining/Ore
- Chemical/Metal (catalytic)
- Reduction and refining/metal (non-catalytic)

Segmentation of total domestic demand in 1983 for each economic sector by PGM product form is shown in Figure H-5. In addition, the segmentation of total domestic demand into estimated DOD & essential civilian demand (D*) and civilian demand (D_3) allows the computation of PGM domestic demand on a process/product form basis also shown in Figure H-5.

PLATINUM CAPACITY ANALYSIS

PGM vulnerability analysis data segmentation of total U.S. domestic PGM demand into estimated DOD and essential civilian demand categories in Appendix A, breakdown of U.S. PGM demand by process/product form in Figure H-5 along with supply and capacity estimates are compiled and consolidated in Table H-1. This data is used to generate U.S domestic demand/domestic capacity ratios in Table H-2 to perform the capacity vulnerability analyses for PGM.

Platinum Vulnerability Analysis

Capacity vulnerability analysis charts for the production of PGM bearing ore, PGM metal (catalytic), and PGM metal (other) are shown in Figure H-6 through H-8, respectively. A comparison of all PGM forms on one vulnerability chart is shown in Figure H-9. PGM production capacity vulnerability has been segmented into five categories--not vulnerable, slightly vulnerable, vulnerable, very vulnerable, and extremely vulnerable as indicated in Table H-3. PGM mining capacity falls into the "extremely vulnerable" category primarily due to the lack of high-grade deposits of PGM bearing ores in the U.S. PGM ores or concentrates are the only product form that falls into this category. Primary and secondary production refining capacity for PGM metals (both catalytic and non-catalytic applications) appears adequate for domestic demand, leading to "not vulnerable" categorization for both.

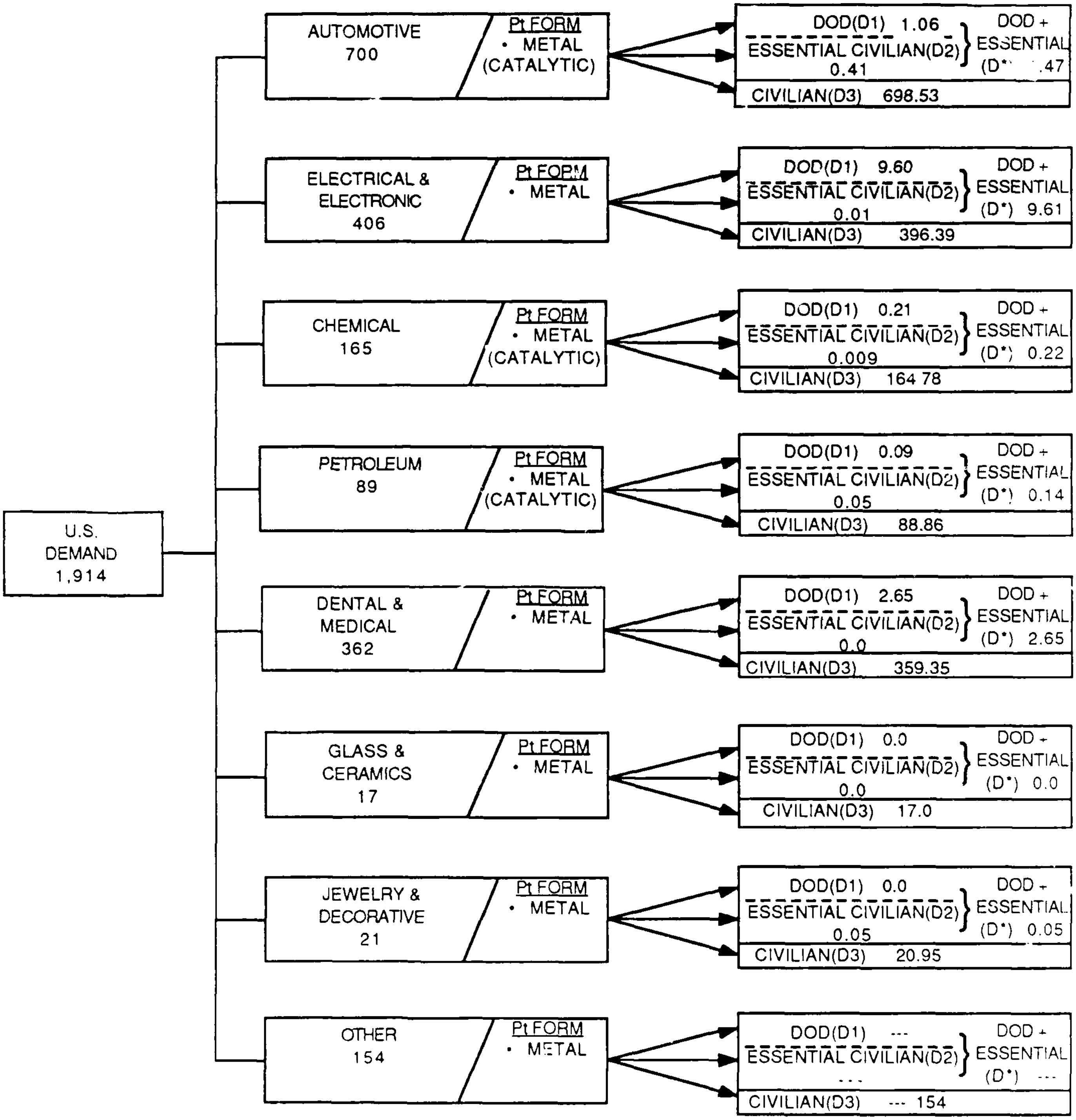
PLATINUM GROUP CAPACITY ANALYSIS SUMMARY

Total estimated U.S. demand for PGM-bearing ores and associated mining capacity was 1.9 million troy ounces (estimate generated by summing metal form demand components) which is around 27% of existing foreign supply. Domestic supply and estimated capacity was 6,000 troy ounces in 1983, or much less than one percent of U.S. demand and less than 50% of estimated DOD and essential civilian demand. Platinum group metal production capacity is estimated at around 1.36 million troy ounces with estimated DOD and essential civilian demand totaling only 14,140 troy ounces (around one percent of estimated capacity).

FIGURE H-5

U.S. PLATINUM-GROUP DEMAND BREAKDOWN

(THOUSAND TROY OUNCES)



Source: U. S. Bureau of Mines and Arthur D. Little, Inc.
Estimates based on Inforum Data

TABLE H-1

PLATINUM-GROUP VULNERABILITY INDEX DATA

THOUSAND TROY OUNCES
(Contained PGM)

PLATINUM-GROUP PRODUCT FORM	PLATINUM-GROUP PROCESS STAGE	TOTAL Pt DEMAND (D_T)	DOD & ESSENTIAL CIVILIAN DEMAND (D^*)	EXISTING &CONVERTIBLE DOMESTIC CAPACITY (C)	DOMESTIC SUPPLY (S)	NON-DOMESTIC SUPPLY	CIVILIAN DEMAND (D_3)
ORE	MINING	1914	14.14**	6	6	7047 e	1899.86
METAL (Catalytic)	CHEMICAL	954	1.83	1363 e	648 e	N.A.	952.17
METAL (Other)	REDUCTION/ REFINING	960	12.31	1307	653 e	N.A.	947.69

Source U S Bureau of Mines

e Arthur D Little estimates based on internal and industry sources

N A Not Available

** Estimate generated by summing metal forms

TABLE H-2

PLATINUM-GROUP DOMESTIC DEMAND/ DOMESTIC CAPACITY RATIOS

	PEACE TIME		INCREASED DEMAND 2X	INCREASED DEMAND 3X	INCREASED DEMAND 4X
	$\frac{D_3}{C}$	$\frac{D^*}{C}$	$\frac{2D^*}{C}$	$\frac{3D^*}{C}$	$\frac{4D^*}{C}$
PGM Ore Mining	316.6	2.36	4.71	7.08	9.44
Platinum Group Metal (Catalytic)	0.70	0.0013	0.0026	0.0039	0.0052
Platinum Group Metal (Other)	0.72	0.009	0.018	0.027	0.036

FIGURE H-6
VULNERABILITY ASSESSMENT
Demand/Capacity Balance: Platinum Ore Mining

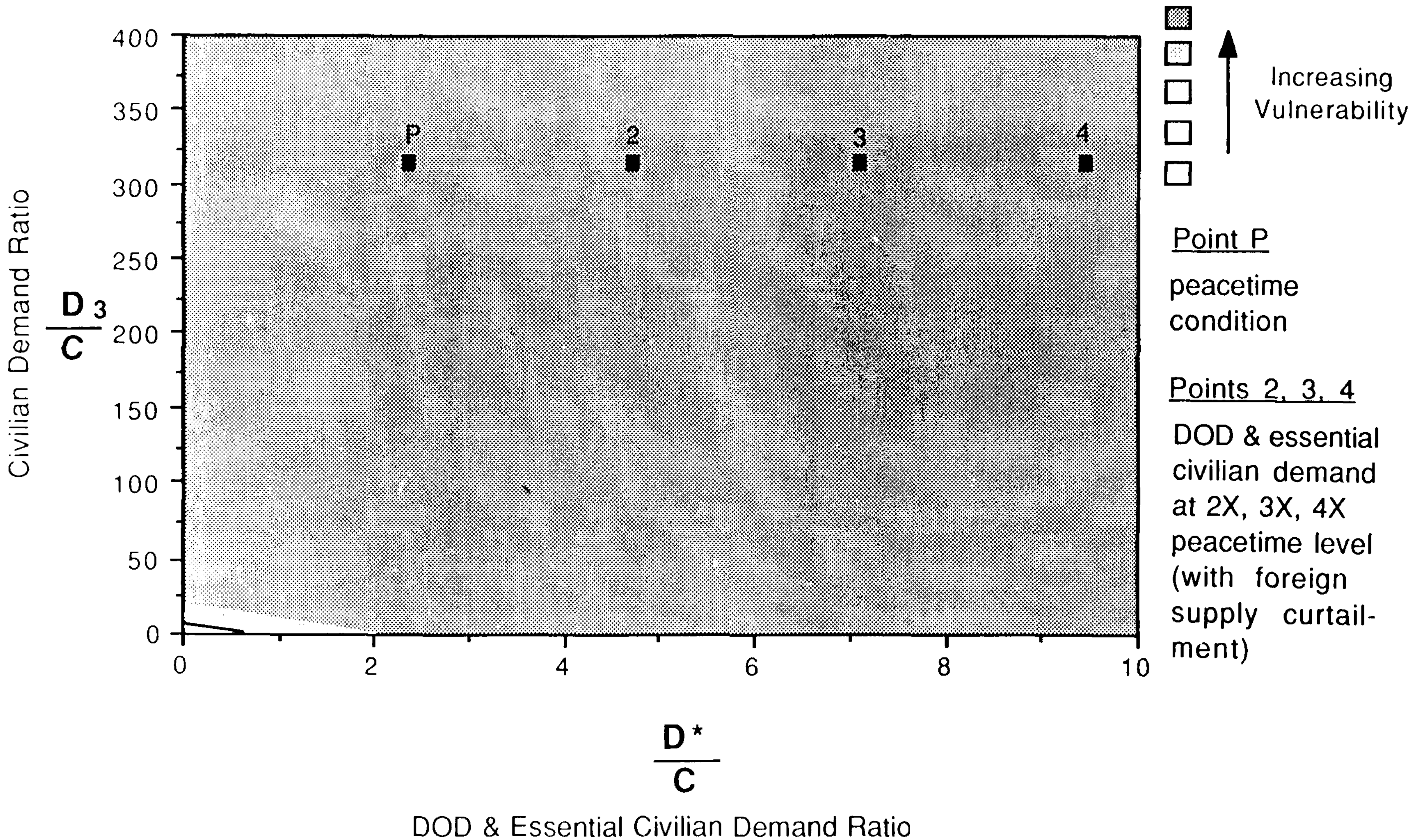


FIGURE H-7

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Platinum Metal (Catalytic)

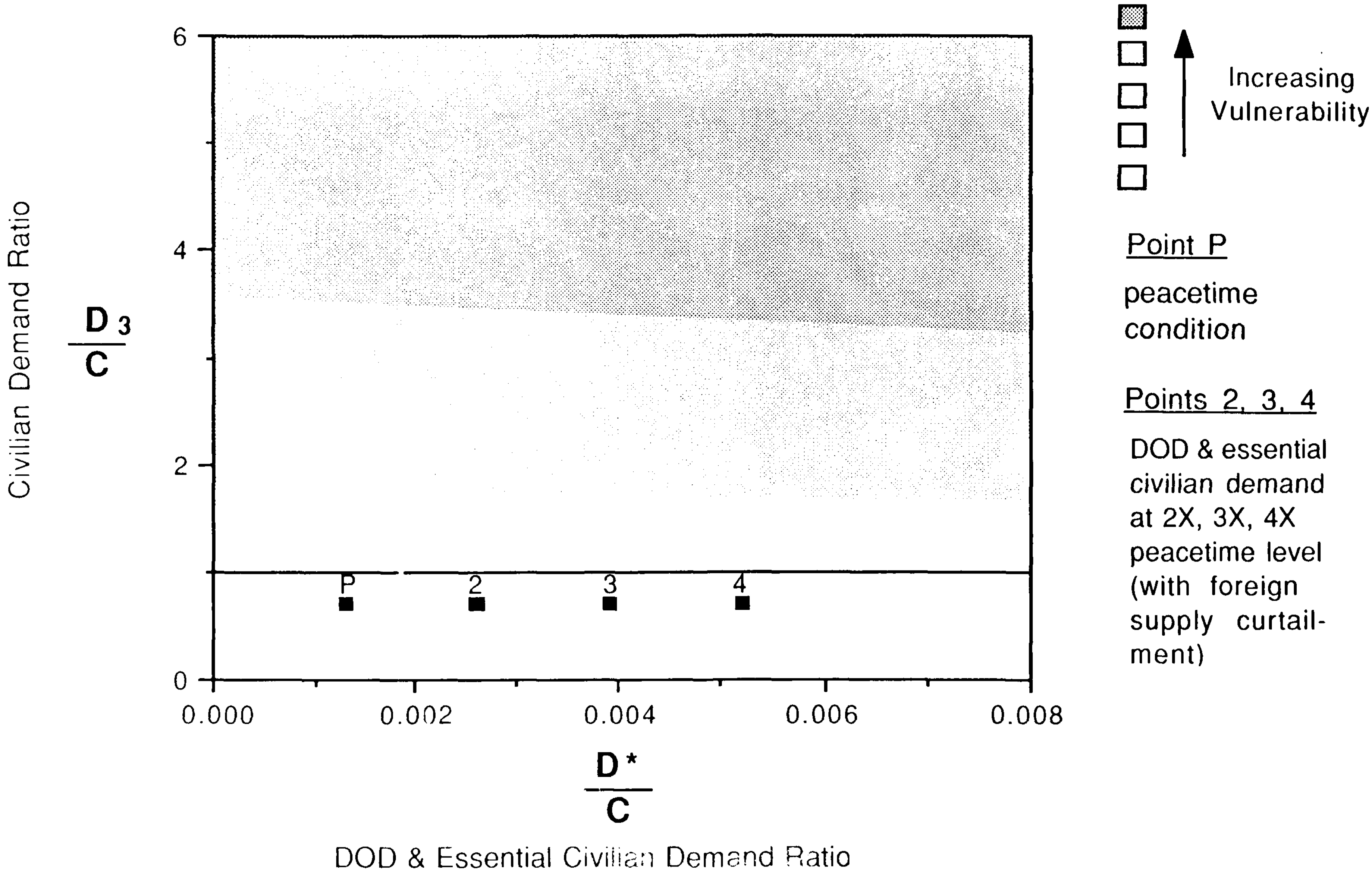
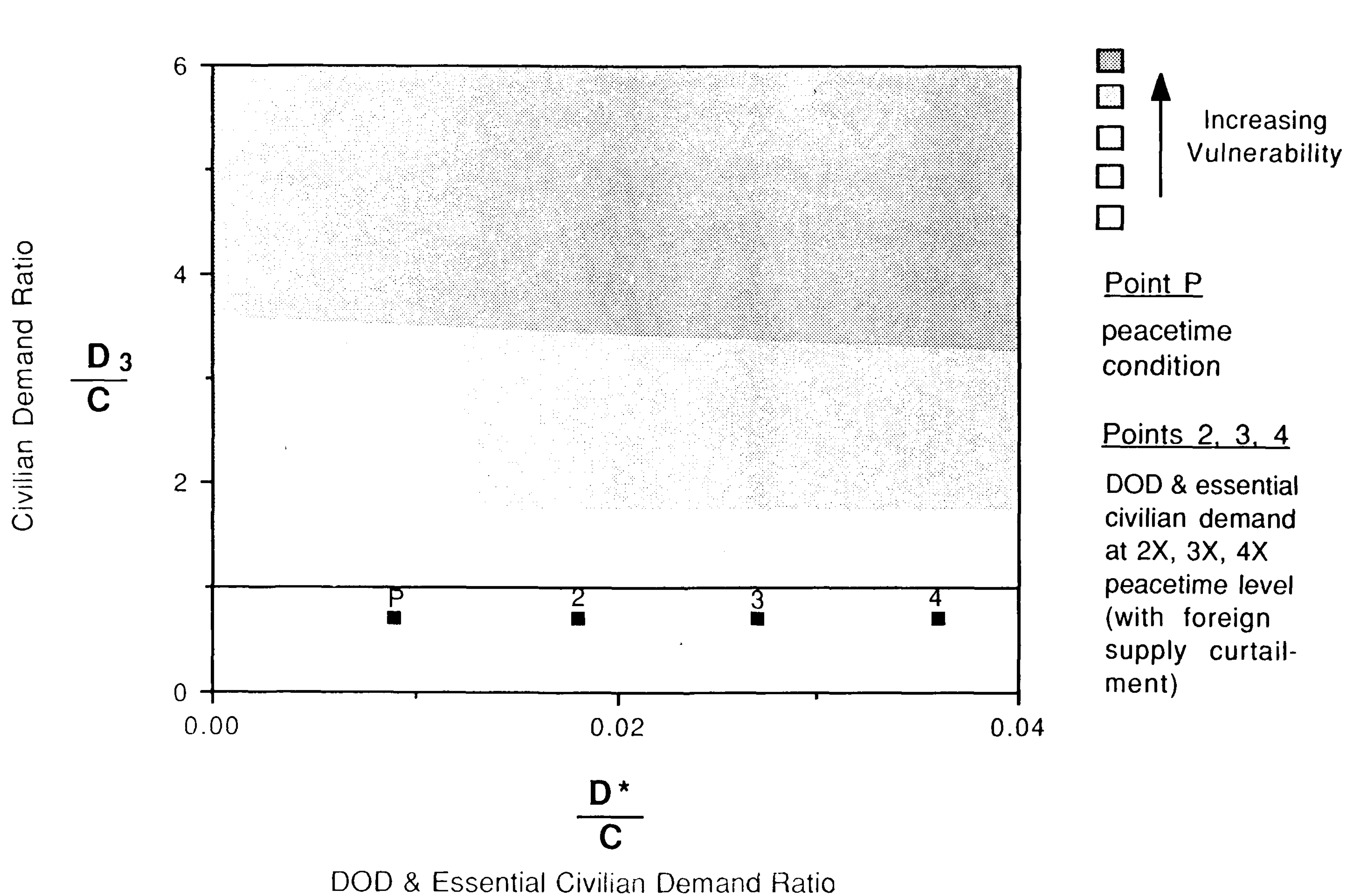


FIGURE H-8

VULNERABILITY ASSESSMENT

Demand/Capacity Balance: Platinum Metal (Other)



Point P

peacetime condition

Points 2, 3, 4

DOD & essential civilian demand at 2X, 3X, 4X peacetime level (with foreign supply curtailment)

FIGURE H-9

VULNERABILITY ASSESSMENT

Process/Form Comparison for Platinum

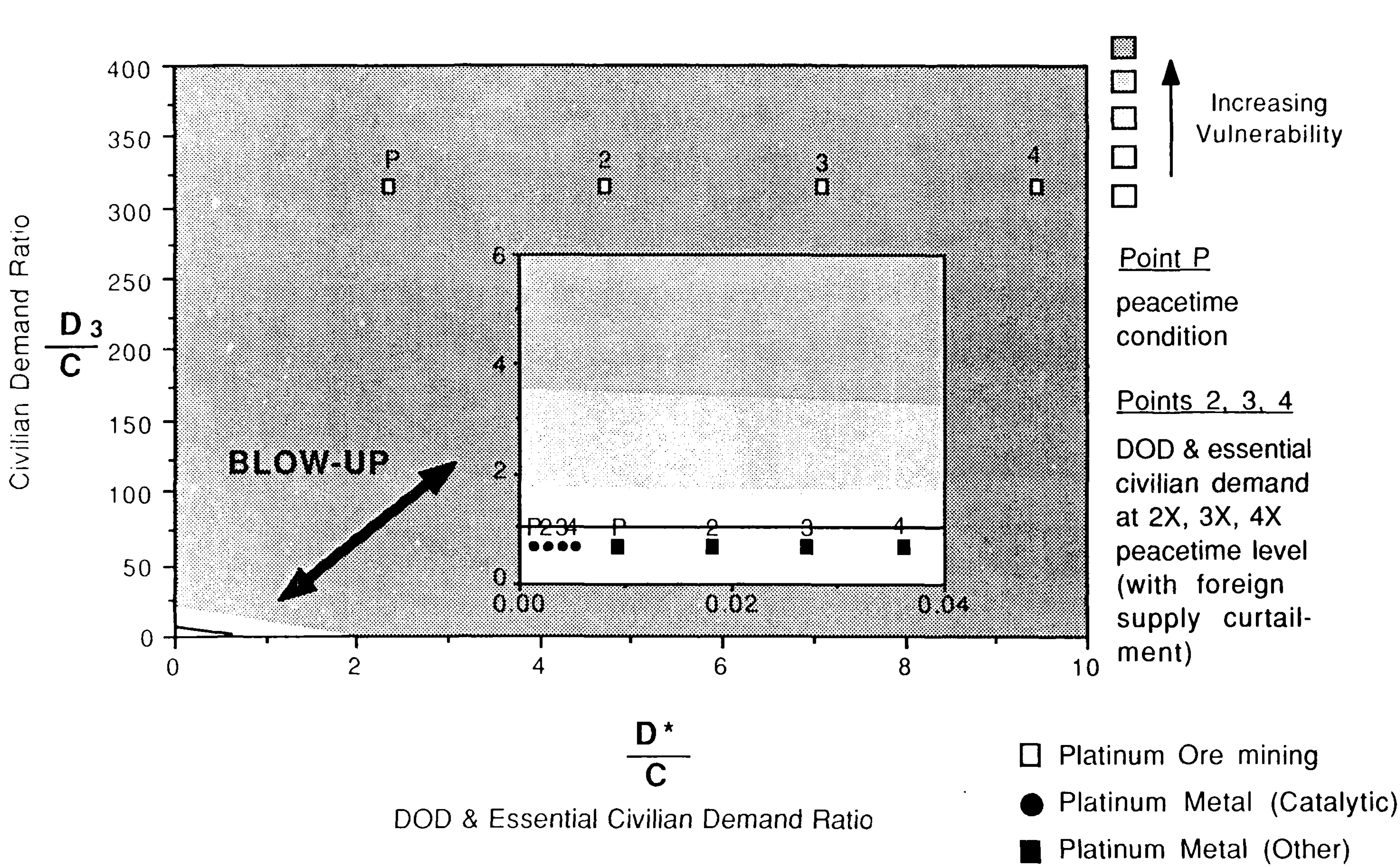


TABLE H-3
PLATINUM GROUP DOMESTIC CAPACITY ANALYSIS SUMMARY

RELATIVE VULNERABILITY INDEX

PLATINUM

INCREASING VULNERABILITY →

PROCESS	PRODUCT FORM	NOT VULNERABLE	SLIGHTLY VULNERABLE	VULNERABLE	VERY VULNERABLE	EXTREMELY VULNERABLE
MINING	ORE					P, 2, 3, 4
CHEMICAL	METALS (CATALYTIC)	P, 2, 3, 4				
REDUCTION/ REFINING	METALS (OTHER)	P, 2, 3, 4				

P - PEACETIME
2 - DEMAND (2X PEACETIME DEMAND)
3 - DEMAND (3X PEACETIME DEMAND)
4 - DEMAND (4X PEACETIME DEMAND)

Looking at the platinum group product form flowsheet in Figure H-10, as with many of the other strategic and critical materials previously analyzed, the process/product capacity "pinchpoint" is at the front end of the supply process, namely PGM ore bodies/mining capacity. This PGM flowsheet also slows the basic unit operations/processes that supply end-use demand such as electronic devices, dental, jewelry, automotive catalysts, etc. PGM recycle flows are also indicated (a discussion of these flows was addressed earlier in this appendix).

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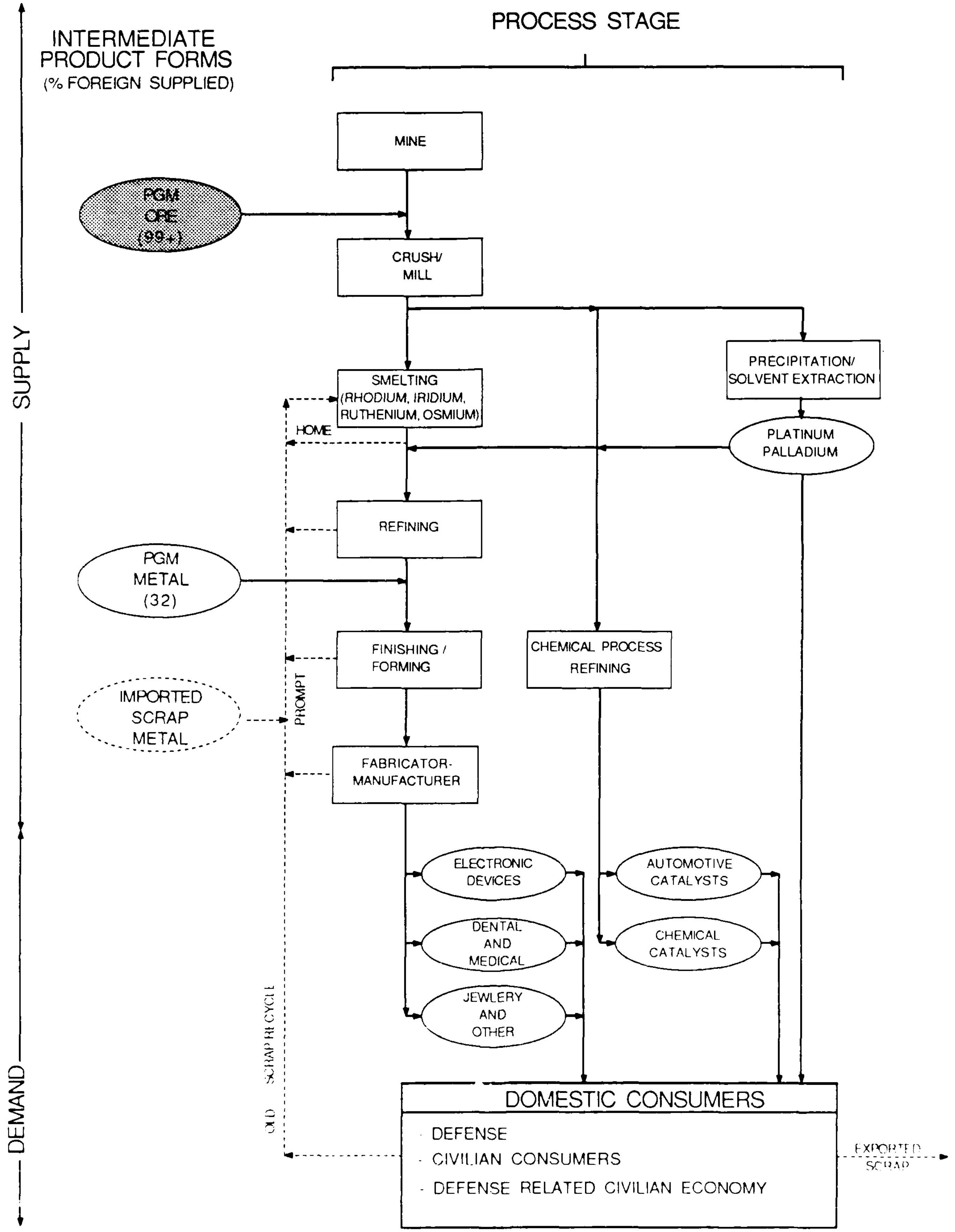
6. Hennion, F.J., J.J. de Barbadillo, J.H. Weber, and G.A. Mills. Use of Critical Materials in Catalysts for the Petroleum and Chemical Industries (Cobalt and Platinum Group Metals). U.S. Congress, Office of Technology Assessment Contract 333-8480.0, Irico Research and Development Center Inc., December 16, 1983, 113 pp.

FIGURE H-10
PLATINUM GROUP PRODUCT FORM FLOWSHEET



APPENDIX I

RUBBER INDUSTRY OVERVIEW AND GEOGRAPHIC DISTRIBUTION

Issues surrounding natural rubber are rather different than the other mineral commodities discussed in this report. Like other mineral commodities, a number of competitive materials have been developed for natural rubber (plastics, synthetic rubber, etc.). However, unlike the mineral commodities, rubber is a renewable resource that can be harvested from plants. Historically, rubber plants have been a source of commercial rubber in the United States and there is a continuing interest in natural rubber because of:

- its unique properties in some applications such as airplane tires and tank treads;
- there is no domestic commercial production of natural rubber today and it thus poses concerns about its availability under mobilization conditions.

An overview of the rubber situation was provided in an NAS study (Guayule: an Alternative Source of Natural Rubber, Washington, DC. 1977). Relevant sections are quoted below.

"Of some 2,000 species of plants known to contain rubber, only a few have ever produced it in substantial quantities for commercial use. Two of these, the rubber tree Hevea brasilensis (grown principally in Southeast Asia) and the guayule shrub Parthenium argentatum Gray (which grows wild in some semiarid regions of North America), have been continuing sources of commercial rubber. In contrast to the majestic Hevea tree, guayule (a Spanish corruption of an Aztec word, usually pronounced wy-oo-lee) is an inconspicuous shrub less than 3 ft (1 m) tall. The two plants also have contrasting climatic requirements: Hevea is native to equatorial lowland rain forest regions in the Amazon basin; guayule comes from upland plateaus in Mexico and Texas with subtropical-temperature climates, where rainfall is low and erratic."

However, the rubber industry has long known that the two plants, despite these differences, produce a similar rubber. Indeed, in 1910 guayule provided 10 percent of the world's natural rubber and continued to be a minor source of commercial natural rubber for almost 40 years more. However, after World War II-during which a giant guayule-growing program, The Emergency Rubber Project, was conducted by the U.S. Forest Service cultivation of the plant was abandoned. The consensus in 1946 was that there was little need for another rubber source; hevea rubber was in good supply and under no threat from a hostile enemy. Furthermore, it was erroneously believed that man-made elastomers would make natural rubber obsolete.

But the outlook has since changed:

> Hevea rubber shows no likelihood of being rendered obsolete by man-made rubber and, in fact, has retained its position as one of the world's most important commodities. There is an ever-increasing demand for natural rubber.

NATURAL RUBBER SUPPLY/DEMAND RELATIONSHIPS

As recently noted (see Figure I-1), natural rubbers' share of total rubber use has increased slowly from less than 25% in 1977 to more than 28% last year, owing mainly to the decline in consumption of synthetic rubber. Now that crude oil prices are holding at about two thirds the price prevailing in the first half of the decade, the gain in natural rubber's share of consumption may slow this year. Because negligible amounts of hydrocarbons and energy are used in producing natural rubber, its cost has increased more slowly than that of synthetic rubbers. The shift to radial tires has added to demand for natural rubber because of it slower heat buildup during flexing. Nevertheless, in absolute terms, rubber consumption by manufacturers has declined steadily in the U.S. during the past 10 years, from more than 3.2 million metric tons in 1977 to just over 2.6 million metric tons last year. The decline has occurred in synthetic rubber, with the demand in 1986 at 1.87 million metric tons, down nearly a quarter from the 1977 demand of 2.46 million metric tons. Consumption of natural rubber, however, has remained nearly constant, at 750,000 metric tons last year, as it did the two preceding years compared to about 710,000 million in the mid 1970's. World demand (including Western World and Centrally Planned Economies) is about 4 million tons (C&EN, Mar. 21, 1988).

Table I-1 shows that tires have constituted about three-quarters of the demand for natural rubber.

NATURAL RUBBER APPLICATIONS AND CHARACTERISTICS

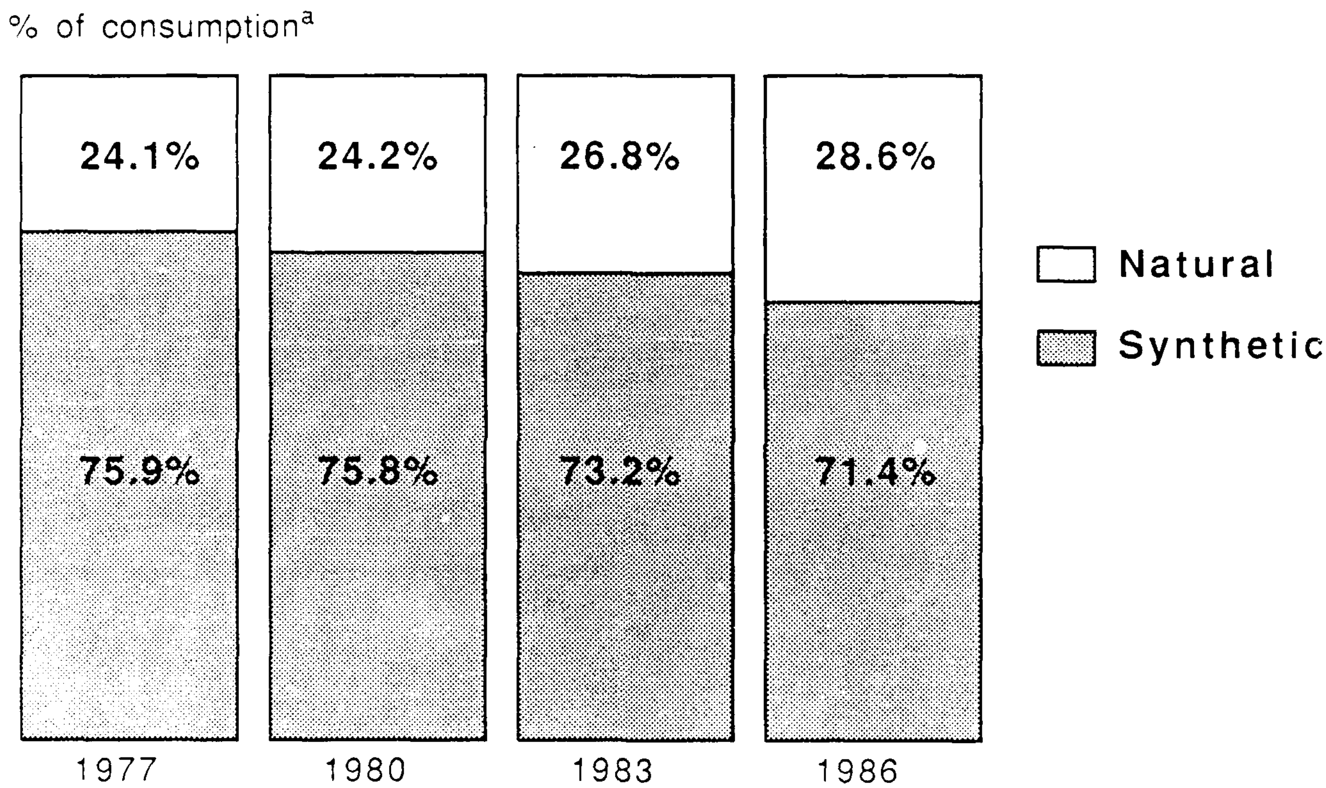
In short, natural rubber is still preferred in applications that demand elasticity resilience, tackiness, and low heat buildup. It is indispensable in applications where heat buildup under severe conditions could cause failure such as as tires (bus, truck, and airplane) and tank treads. Thus, there is a natural strategic concern about the suitability of natural rubber that can be grown domestically. As noted by the previously cited NAS report:

- "Both guayule rubber and hevea rubber are hydrocarbons, both are polymers of isoprene, both have double bonds with a cis configuration (this gives the rubber its "bounce"), both are approximately the same in molecular length and weight. Both have very similar, or identical, microstructure; studies have not detected any differences even with techniques that can detect as little as 0.5 percent of structural difference. In both guayule rubber and hevea rubber the isoprene units are extremely regular: they are all joined end to end. There is no evidence for any aberrant connections in which a isoprene is not joined end-to-end or in which the double bonds have a trans-configuration."

- "No difficulties are expected in manufacturing goods form guayule rubber; standard equipment can be used. It vulcanizes like hevea rubber, it has properties that allow it to flow properly in molds

FIGURE I-1

Natural Rubber Slowly Gains in Share of U.S. Elastomer Use



[a] Excludes reclaimed. Source: C&EN May 18, 1987

TABLE I-1

ESTIMATED NATURAL RUBBER CONSUMPTION
IN THE UNITED STATES

Consumption (m tons/yr) in 1992 projected	871
Consumption (m tons/yr) in 1987 projected	872
Consumption (m tons/yr) in 1973 projected	710

Product	Percent
Passenger car tires	26.6
Truck/bus tires	42.9
Other tires	7.0
Total for tires	76.5
Footwear	2.1
Hose and belting	4.2
Other fabricated goods	11.8
Other products	5.4
Total	100.0

Source: Chemical and Engineering News, March 21, 1988
Guayule, National Academy of Sciences, Washington, DC, 1977

and extruders, and like hevea rubber, it has the natural tack crucial for the manufacture."

- "Both hevea and guayule rubbers are excellent polymers and, provided their prices are competitive, will be preferred over synthetic elastomers in many cases. For example, most hevea rubber is used in tire carcasses because it resists heat buildup and thus suffers less heat-induced degradation."

  Natural rubber prices are limited by synthetic rubber prices for, though a loss in quality may result, manufacturers can substitute synthetic for natural rubber in their products if necessary. Nonetheless, it is almost universally predicted by rubber economists that hevea rubber (and synthetic polyisoprene rubbers) will continue to command premium prices over other elastomers.

NATURAL RUBBER VUNERABILITY ANALYSIS

From the viewpoint of this study, it should be recognized that there is no equivalent information such as Bureau of Mines of INFORUM data on natural rubber. Thus, one has to rely on prior publications and trade press information to make assessments on natural rubber.

- Since there is almost insignificant domestic capacity to grow guayule rubber raw material, natural rubber capacity, C=0, a vulnerability map would indicate the U.S. is extremely vulnerable.

- As noted earlier, there is the ability to use existing equipment for manufacture of guayule rubber products. In addition, there exists excess tire-making capacity today. As a result, there does not appear to be any capacity constraints downstream from the raw material natural rubber "pinchpoint."

APPENDIX J

Appendix J is a selected information directory of relevant articles, reports, bulletins, etc., that were compiled by Arthur D. Little, Inc. for the various strategic and critical materials.

The literature in this directory is categorized into six subject areas covered regarding one or several strategic and critical materials:

- substitution
- conservation
- policy
- supply
- recycling
- R&D efforts

This directory lists information sources by author, title of the report or article, year of publication and critical materials covered in the publication. (In addition, Column 2 shows whether an abstract is available with the report.)

INFORMATION DIRECTORY/CATALOGUE

SUBJECT	ABSTR	AUTHOR	TITLE	YR	Co	Cr	Mn	Pt-Gr	Rub	Ti
					Critical Materials					
Substitution										
	Y	Clark, J.	Potential of Composite Mat. to Replace Cr, Co and Mg in Critical Applications	85	1	1	1			
	Y	Charles River Assoc, Inc.	Scarcity, Recycling & Substit. of Pot. Scarce Mat. Used for Veh. Emissions Cont	82		1	1	1		
	Y	NATO Com. Study Group 1976	Rational Use of Potentially Scarce Materials	76	1			1		
	Y	Chaney, R.E.	Strategic and Critical Materials Progess Annual Report 1985	85				1		
	Y	Hilare, G.	Problemes Poses Par L'Introducion Des Materiaux Nouveau	84						1
	Y	Balandrin, M.F., et al	Whole Plant Utilization of Sunflowers as a Renewable Source of Strat. Mat.	85					1	
	Y	N.M.A.B.	Contingency Plans for Chromium Utilization	78						
	Y	Stephens, J.R.	A Status Review of NASA's COSAM Program	82	1	1				
	Y	Anonymous	Conservation and Substitution Technology for Critical Material Vol I	81						
	Y	Anonymous	Potential Impact of Fiber Optics on Copper Consumption	84						
	Y	Gray, Dr. A.G.	Substitution and Conservation Technology for Chromium	83		1				
	Y	N.M.A.B.	Cobalt Conservation Through Technological Alternatives	83	1					
	Y	N.M.A.B.	Reliability of Ceramics for Heat Engine Applications	80						
	Y	U.S.D.A. Crit. Mat Task Force	Growing Industrial Materials: Renewable Resources from Agriculture	84					1	
	N	Caruana, C.M.	Fiber Optics at Bell Labs	87		1				
	N	Goeller, H.E., Weinberg, A.M.	Age of Substitutability	76	1	1	1			1
	N	Stephens, J.R. et al	Replacing Crit. & Strat. Refractory Metal Elements in Nickel-Based Superalloys	84		1				
	N	Off. Tech Assesment, US Congr.	Plants: The Potential for Extracting Protien, Medicines & other Useful Chem.	83					1	
	N	Wachtman, J.B. Jr.	U.S. Dept. of Commerce Public Workshop on Crit. Mat. Needs in the Aerospace Ind.	81	1	1				1
	N	Anonymous	Standard Industrial Classification 30: Rubber and Plastic Products Industry	85						
	N	Mehrabian, R. et al	Technical Aspects of Critical Materials Use by the Steel Industry	83		1				
	N	NASA Lewis Res. Cent.	Conservation of Strategic Aerospace Materials	82						
	N	Charles River Assoc, Inc.	Economic Analysis of the Chromium Industry	70		1				
	N	Anonymous	Guayule: An Alternative Source of Natural Rubber	77					1	
	N	ADL, Inc.	Strategic and Critical Materials	81	1	1	1			
	N	Fangmeier, D. et al	Guayule for Rubber Production in Arizona	NA					1	
Conservation										
	Y	Foster, R.J.	Tech. Alter. for the Conser. of Strat. & Crit. Minerals-Co ,Cr ,Mg ,& Pt-Group Met.	85	1	1	1	1		
	Y	Stephens, J.R.	A Status Review of NASA's COSAM Program	82	1	1				
	Y	N.M.A.B.	Cobalt Conservation Through Technological Alternatives	83	1					1
	Y	Anonymous	Conservation and Substitution Technology for Critical Material Vol I	81						
	Y	Chaney, R.E.	Strategic and Critical Materials Progess Annual Report 1985	85				1		
	Y	Charles River Assoc, Inc.	Scarcity, Recycling & Substit. of Pot. Scarce Mat. Used for Veh. Emissions Cont	82		1	1	1		
	Y	Gray, Dr. A.G.	Substitution and Conservation Technology for Chromium	83		1				
	Y	NATO Com. Study Group 1976	Rational Use of Potentially Scarce Materials	76	1			1		
	Y	Spague, R.A.	Gas Turbine Engine Design Consider. as Rel. to Alloys of High Crit. Element Cont.	84	1	1				
	N	Wachtman, J.B. Jr.	U.S. Dept. of Commerce Public Workshop on Crit. Mat. Needs in the Aerospace Ind.	81	1	1				1
	N	Anonymous	Cost of Substitution for Scarce Resources in an Industrial Economy	80						
	N	Bureau of Mines	Materials and Recycling Technology	87		1				
	N	NASA Lewis Res. Cent.	Conservation of Strategic Aerospace Materials	82						
	N	Bever, M.B.; Nasar, S.	Materials, Technological Change and Productivity	82						
	N	Kinner, W.K.	Rapid Quenching: A Materials Bonanza?	79						
	N	Van Arsdel, W.B.	The Industrial Market for Farm Products	40						
	N	Sousa. L.J.	Summary of Technical Innvo. in the U.S. Copper Industry	83						
	N	Syre, S.	U.S. Researchers Taking a Closer Look at "Poor Ores"	NA						
	N	Szekely, J.	Toward Radical Changes in Steelmaking	79						
Policy										
	Y	Strishkov, V.V., Steblez, W.G.	The Chromium Industry in U.S.S.R.	85		1				
	Y	US Congress House of Rep.	National Inst. for New Agricultural and Forestry Industrial Mat. Act of 1987	87						
	Y	Com. Nat. Mat Policy Plan Proc	National Non-Fuel Minerals Policy Planning Process	81						

SUBJECT	ABSTR	AUTHOR	TITLE	YR	Co	Cr	Mn	Pt-Gr	Rub	Ti
					Critical Materials					
	Y	Roskill Info Serv. Ltd.	The Economics of Chromium 1985	85		1				
	Y	Com. Tech Crit. & Strat. Mat	Potentially Critical Materials	77		1				
	Y	Long, T.P., McClam, T.J.	Strategic Materials: A Crisis Waiting to Happen	84	1	1	1			1
	N	Charles River Assoc, Inc.	Economic Analysis of the Chromium Industry	70		1				
	N	97th Congress; 2nd Session	U.S. Economic Dependence on Six Imported Strategic Non-Fuel Materials	82	1	1	1	1		
	N	Roskill Info Serv. Ltd.	The Economics of Cobalt	NA	1	1	1	1		
	N	Scott, D.	Net Present Val. Model for Optimizing Disposal of Excess Nat. Def. Stock. Mat.	NA						
	N	Roskill Info Serv. Ltd.	Roskill Studies on Metals and Minerals(various elements)	NA						1
	N	98th Congress, 1st Session	National Critical Materials Act of 1983	83						
	N	Roskill Info Serv. Ltd.	The Economics of Manganese	NA	1					
	N	Bureau of Indust Eco.	Market Trends and Forecasts for Selected Strategic Materials	83	1					1
	N	Roskill Info Serv. Ltd.	The Economics of Titanium	NA				1		
	N	98th Congress, 1st Session	Foresight in the Private Sector: How can Government Use It?	83						
	N	Schink, G.R.	Impacts on the US Economy of Tot. Mobilization and 25% Cut in World Oil Sup.	86						
	N	98th Congress, 1st Session	Artic Research and Policy Act of 1983	83						
	N	96th Congress, 1st Session	The Materials Policy, Research and Development Act of 1979	79						
	N	95th Congress; 1st Session	Resource Recovery Implementation: Engineering and Economics	76						
	N	Anonymous	Congressional Workshop on Materials Research and Development	85					1	
	N	Anonymous	Materials and National issues Conference- Proceedings	77						
	N	Brown, G.F.Jr.	Measuring DoD Impacts on the Economy	86						
	N	Proceedings Eng. Found. Conf.	Engineering Implications of the Chronic Materials Scarcity	77						
	N	Roskill Info Serv. Ltd.	The Economics of Platinum-Group Metals	NA			1			
	N	Ad Hoc Com. on Opp. in Bas Mat	Problems and Legislation Opportunities in the Basic Materials Industries	75						
	N	98th Congress, 1st Session	Seventh Biennial Conference on National Materials Policy	83	1	1	1	1		
	N	Science Policy Res. Div.	Materials Policy Handbook	77						
	N	Anonymous	Report on the Issues Indentified in the Nonfuel Minerals Policy Review	79						
	N	Comptroller General, US	Implementation of the National Min. and Mat. Policy Needs Better Coord. and Focus	84						
	N	97th Congress; 2nd Session	Hearings bef. the Subcom. on Transportation, Aviation and Materials	82						
	N	Wachtman, J.B. Jr.	U.S. Dept. of Commerce Public Workshop on Crit. Mat. Needs in the Aerospace Ind.	81	1	1				1
	N	Comptroller General, US	Conditions that Limit Using Barter and Exchange to Acquire Nat. Def. Stock. Mat.	83						
		ADL, Inc. & Syll., Inc.	A Study of the Effect of Foreign Dependency	84						
Supply										
	Y	Strishkov, V.V., Steblez, W.G.	The Chromium Industry in U.S.S.R.	85		1				
	Y	N.M.A.B. Panel on Cr	Trends in the Usage of Chromium	NA		1				
	Y	Div. Minerals Policy & Analy.	South Africa and Critical Materials	86	1	1	1			
	Y	N.M.A.B.	Basic and Strategic Metals Industries: Threats and Oppurnities	85						
	Y	N.M.A.B.	Manganese Reserves and Resources of the World & Their Industrial Implications	81			1			
	Y	Kilgore, C.C., Thomas, P.R.	Manganese Availibility-Domestic	82			1			
	Y	Faucett, J. et al	Changes in Worldwide Demand for Metals	86						
	Y	ASM	Assessment of Quality and Material Form of Nickel for the Nat. Def. Stock.	86						
	Y	N.M.A.B.	Identification of Critical and Strategic Materials for Naval Combat Systems	81						
	Y	Kirk, W.S.	Cobalt: Mineral Commodity Profiles 1983	83	1					
	Y	ASM Panel	Assessment of Quality and Material Form of Columbium for the Nat. Def. Stock.	NA						
	Y	Koopmans, T. et al	Materials Modeling: An Interdisciplinary Study of the Depletion of Nat. Res.	NA						
	Y	Coffman, J.S., Palencia, C.M.	Manganese Availibility - Market Economy Countries	84			1			
	Y	N.M.A.B.	Assessment of Selected Materials Issues(Supply-Steel, titan., Al, Co,..)	81	1					1
	Y	Coffman, J.S. et al	Minerals Availibility-Manganese Deposit Abstracts	84			1			
	Y	Newell, R. et al	A Review of Methods for Indentifying Scrap Metals	82						
	Y	N.M.A.B.	Supply and Use Patterns for the Platinium-Group Metals	80				1		
	Y	ASM	Assessment of Quality and Material Form of Tantalum for the Nat. Def. Stockpile	86						
	Y	N.M.A.B.	Cobalt Conservation Through Technological Alternatives	83	1					

SUBJECT	ABSTR	AUTHOR	TITLE	YR	Co	Cr	Mn	Pt-Gr	Rub	Ti
	Y	Long, T.P., McClam, T.J.	Strategic Materials: A Crisis Waiting to Happen	84	1	1	1			
	Y	Curwick, L.R. et al	Availibility of Critical Scrap Metals Containing Chromiun in the US (Superalloys)	80		1				
	Y	ASM	Assessment of Quality and Material Form of Vanadium for the Nat. Def. Stockpile	86						
	Y	N.M.A.B.	Contingency Plans for Chromium Utilization	78		1				
	Y	Chaney, R.E.	Strategic and Critical Materials Progess Annual Report 1985	85				1		
	Y	Yasnowsky, P.N., Graham, A.P.	Mineral Depletion Allowances and U.S. Import Dependence	80	1	1	1	1		
	Y	N.M.A.B. Panel on Ferroalloys	Trends in the Use of Ferroalloy by the Steel Industry of the U.S.	71		1				
	Y	N.M.A.B.	Titanium: Past, Present and Future	83						1
	Y	Minerals Data Working Gr.	Minerals Data Source Directory	82	1	1	1	1		1
	Y	Com. Tech Crit. & Strat. Mat	Potentially Critical Materials	77		1				
	Y	Mishra, C. et al	Cobalt Availibility- Market Economy Countries	85	1					
	Y	N.M.A.B.	Considerations in Choice of Form for the Materials for the National Stockpile	82						
	Y	ASM	Assessment of Quality and Material Form of Columbium for the Nat. Def. Stock.	86						
	Y	N.M.A.B.	Quartz for the National Defense Stockpile	85						
	Y	ASM	Quality Assessment of Chromium Metal For the National Defense Stockpile Inventory	84		1				
	N	Greek, B.F.	Global Rubber Industry Resumes Growth Trend	86					1	
	N	Rice, W.L.	Minerals Availibility Cobalt Deposit Abstracts	84	1					
	N	Morning, J.L.	Chromium-1977	77		1				
	N	Anonymous	Technical Aspects of Critical Materials Use by the Steel Industry Vol II	83						
	N	Anonymous	Aluminum Production Technology	80						
	N	97th Congress; 2nd Session	U.S. Economic Dependence on Six Imported Strategic Non-Fuel Materials	82	1	1	1	1		
	N	ADL, Inc.	Strategic and Critical Materials	81	1	1	1	1		1
	N	Anonymous	114th Annual Survey and Outlook for World Mineral Commodities	83	1	1	1	1		1
	N	ADL, Inc. & Syll., Inc.	Ident. of Cost-Effective Opt. to Enhance US Indust. Mobilization Pot.	83						
	N	Anonymous	Chemicals and Alied Products	85						
	N	Charles River Assoc, Inc.	Processing Capacity for Critical Materials	84						
	N	US Dept. Commerce	Critical Materials Requirements of the U.S. Steel Industry	83						
	N	N.M.A.B.	Vanadium Supply and Demand Outlook: Panel on Trends in Use of Vanadium	78						
	N	Hunter, W.L., Kingston, G.A.	Ferrochromium From Western Metallurgical- Grade Content	61		1				
	N	Charles River Assoc, Inc.	Economic Analysis of the Chromium Industry	70		1				
	N	Anonymous	Report on the Issues Indentified in the Nonfuel Minerals Policy Review	79	1	1	1			
	N	Silverman, A. et al	Strat. and Crit. Mineral Pos. of the US with Respect to Cr, Ni, Co, Mg, and Pt.	83	1	1	1	1		
	N	F.E.M.A.	Stockpile Report to the Congress - April - Sept. 1985	85	1		1		1	1
	N	Higgins, J.K.	International Minerals / Metals Review	80	1	1	1	1		
	N	Morning, J.L.	Chromium	76		1				
	N	F.E.M.A.	An Analysis of Domestic Steel Plate Rolling Capacity	85						
	N	Stinson, S.C.	Rubber-Processing Chemicals Recover After 20-Year Low	83					1	
	N	F.E.M.A.	Alternative U.S. Policies for Reducing the Effects of a Cobalt Sup. Disruption-Net Ec	82	1					
	N	Watson, G.A.	Outlook for the US Ferroalloy Industry	84		1	1			
	N	Office of Preparedness	Strategic and Critical Materials: Descriptive Data	83	1	1	1	1	1	1
	N	US General Accounting Office	Actions Needed to Promote a Stable Supply of Strategic and Critical Materials	82						
	N	Brobst, D.A., Pratt, W.P.	United States Mineral Resources	73	1	1	1	1		
	N	Anonymous	Industry's Scramble for Cobalt Supplies	78	1					
	N	O'Shaughnessy, D.P.	Chrome Ore Preparation	82		1				
	N	Block, E. et al	Critical Industry Repair and Reclamation: U.S. Rubber Industry	86					1	
	N	Morgan, J.D., Jr.	The Mineral Position of The U.S.	76	1	1	1	1		1
	N	Jones, T.S.	Manganese: Mineral Commodity Porfiles	83						
	N	Mihalisin, J.R.	Conservation of Materials at the Howmet Turbine Comp. - Corp. Alloy Div.	NA	1	1	1	1		
	N	Everest Consult & CRU Consult	Non-Ferrous Smelter Industry: Clean Air Study	NA		1				
	N	Penner, P., Spek, J.K.	Stockpile Optimization: Energy and Versality Consid. for Strag. & Crit. Mat.	76		1	1			

SUBJECT	ABSTR	AUTHOR	TITLE	YR	Co	Cr	Mn	Pt-Gr	Rub	Ti
					Critical Materials					
Recycling										
	Y	Bever, M.B.	Review of Scrap Metal Recovery	80	1					
	Y	Bever, M.B.	The Impact of Materials and Design Changes on the Recycling of Automobiles	80						
	Y	Bever, M.B.	Systems Aspects of Materials Recycling	78						
	Y	Chambers, D.H., Dunning, B.W.	Silver Recovery From Aircraft Scrap	80						
	N	Bureau of Mines	Materials and Recycling Technology	87	1	1				1
	N	Wachtman, J.B. Jr.	U.S. Dept. of Commerce Public Workshop on Crit. Mat. Needs in the Aerospace Ind.	81	1	1				1
	N	Yafie, R.C.	Used Beverage Cans Retain Position as the Mainstay In Recycling of Aluminum	83						
	N	Bever, M.B.	Recycling in the Materials System	77				1		
	N	Anonymous	Technical Options for Conser. of Metals-Case Studies of Selected Met. and Prod.	79						
R&D Efforts										
	Y	Anonymous	Inventory of Federal Materials Research and Technology-1982	83						
	Y	Anonymous	Extractive Metallurgy Technology	NA	1	1				1
	Y	NMAB, Com. Mat Substit. Method	Analytical Techniques for Studying Substitution Among Materials	82						
	Y	Koopmans, T. et al	Materials Modeling: An Interdisciplinary Study of the Depletion of Nat. Res.	NA						
	Y	N.M.A.B.	Structural Cermanics	75						
	Y	Chaney, R.E.	Strategic and Critical Materials Progess Annual Report 1985	85				1		
	Y	Bever, M.B.	The Recycling of Metals I, Ferrous Metals	76						
	Y	Bever, M.B.	The Recycling of Metals - II. Non-Ferrous Metals	76						
	Y	N.M.A.B.	An Assessment of the Ceramics R. and D. Efforts of the BuMines	84						
	Y	Horton, R.C., Kenahan, C.B.	New Developments in Materials Recycling	84	1	1				
	N	Charles River Assoc, Inc.	The Pot. for New Metal Processing Techn. to Reduce Consumption of Crit. Metals	83						
	N	Anonymous	Congressional Workshop on Materials Research and Development	85					1	
	N	Higgins, J.K.	International Minerals / Metals Review	80	1	1	1	1		
	N	Anonymous	Report on the Issues Indentified in the Nonfuel Minerals Policy Review	79						
	N	Tien, J.K., Jarrett, R.N.	Pot. for Dev. & Use of New Alloys to Red. Consumpt. of Cr, Co, & Mg for Crit. Appl.	83						
	N	N.M.A.B.	Mutual Substitutability of Aluminum and Copper	72						
	N	Bureau of Mines	Materials and Recycling Technology	87		1				
	N	US Dept. Energy	Materials Sciences Programs Fiscal Year 1982	82						
	N	NATO Advisory Group Aerospace	Materials Substitution and Recycling	83						
	N	Anonymous	Cost of Substitution for Scarce Resources in an Industrial Economy	80						
	N	Am. Consult. Engineers Council	Industrial Market & Energy Management Guide	85					1	
	N	Eager, T.W.	The Real Challenge in Materials Engineering	87						
	N	Clark, J.P., Field, F.R.	How Critical are Critical Materials?	85						
	N	Pederson, J.R.	Bureau of Mines - Research 86	86						